NPS-OC-12-001CR

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

MARINE MAMMAL DEMOGRAPHICS OFF THE OUTER WASHINGTON COAST AND NEAR HAWAII

by

Erin Oleson and John Hildebrand

April 2012

Approved for public release; distribution is unlimited.

Prepared for: Chief of Naval Operations
Energy and Environmental Readiness Division,
Washington, D.C.

THIS PAGE INTENTIONALLY LEFT BLANK

NAVAL POSTGRADUATE SCHOOL
Monterey, California 93943-5000

Daniel T. Oliver
President

Leonard A. Ferrari
Executive Vice President and
Provost

The report entitled *"Marine Mammal Demographics off the Outer Washington Coast and near Hawaii"* was prepared for and funded by the Chief of Naval Operations, Energy and Environmental Readiness Division [CNO(N45)], Washington, D.C. The report was prepared by the Scripps Institution of Oceanography, University of California at San Diego, supported under NPS Grant N00244-08-1-0023.

Further distribution of all or part of this report is authorized.

This report was prepared by:

Erin Oleson
NOAA-NMFS-Pacific Fisheries
Science Center

John Hildebrand
Scripps Institution of Oceanography
UCSD

Reviewed by:

Jeffrey Paduan
Chairman, Department of Oceanography

Released by:

Douglas Fouts
Interim Vice President and
Dean of Research

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From-To)*
11-04-2012	Technical Report	1 June 2008-30 May 2010

4. TITLE AND SUBTITLE

Marine Mammal Demographics off the Outer Washington Coast and near Hawaii

5a. CONTRACT NUMBER

5b. GRANT NUMBER
N00244-08-1-0023

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Erin Oleson and John Hildebrand

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES)

Scripps Institution of Oceanography
University of California at San Diego,
La Jolla, CA 92037

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Sponsoring Agency: Chief of Naval Operations
Energy and Environmental Readiness Division
Washington, DC

Monitoring Agency: Department of Oceanography
Naval Postgraduate School
833 Dyer Rd
Monterey, CA 93943

10. SPONSOR/MONITOR'S ACRONYM(S)
Sponsoring Agency: CNO(N45)

Monitoring Agency: NPS

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

NPS-OC-12-001CR

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES
The views expressed in this report are those of the authors and do not reflect the official policy or position of the Department of Defense or the US Government

14. ABSTRACT

This report summarizes work conducted in 2008-2010 to understand the seasonal occurrence and distribution of marine mammals in or near active Navy ranges off Washington and Hawaii. Long-term acoustic recording and monthly visual surveys have been conducted off the outer Washington coast since 2004 as part of an effort to monitor for marine mammals within the boundaries of the proposed expansion area of the Quinault Underwater Tracking Range (QUTR). This effort was designed to characterize the vocalizations of species present in the area, determine the year-round seasonal presence of all marine mammal species, and evaluate the distribution of marine mammals near the Navy range. Small boat visual surveys were conducted in the range, resulting in sightings of a broad range of marine mammal species throughout the year. Two High-frequency Acoustic Recording Packages (HARPs) have been deployed near the QUTR, data from which provide information on the seasonal presence of a broad range of marine mammal species. In 2008 a long-term acoustic monitoring study off the coast of Hawaii was started in cooperation with regular visual surveys conducted in the region. HARP recordings of tropical odontocetes, which may be used as reference recordings for future long-term monitoring efforts within the Hawaii Range Complex, have also been obtained, providing the first information on the seasonal occurrence of odontocetes in this region gained from long-term passive acoustic monitoring.

15. SUBJECT TERMS
Marine mammals, acoustic surveys, visual surveys, Quinault Underwater Tracking Range, Hawaii Range Complex, HARP, cetaceans, odontocetes, mysticetes, pinnipeds

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Tarry Rago
Unclassified	Unclassified	Unclassified	UU	69	**19b. TELEPHONE NUMBER** *(include area code)* 831-656-3349

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

THIS PAGE INTENTIONALLY LEFT BLANK

Contents

List of Tables

List of Figures

THIS PAGE INTENTIONALLY LEFT BLANK

December 2011

Marine Mammal Demographics off the Outer Washington Coast and Near Hawaii

Final Technical Report for Naval Postgraduate School
Grant Number N00244-08-1-0023
June 1, 2008 – May 30, 2010

UNIVERSITY
OF
CALIFORNIA
SAN DIEGO

SCRIPPS
INSTITUTION
OF
OCEANOGRAPHY

Principal Investigators :

Erin Oleson and John Hildebrand

Scripps Institution of Oceanography

University of California San Diego

MARINE PHYSICAL LABORATORY

Contract Number: N00244-08-1-0023
Project Title: Marine Mammal Demographics off the Outer Washington Coast and Near Hawaii
Project Duration: June 1, 2008 – May 30, 2010

Executive Summary

This report summarizes work conducted in 2008-2010 with Navy support to understand the seasonal occurrence and distribution of marine mammals in or near active Navy ranges. Long-term acoustic recording and monthly visual surveys have been conducted off the outer Washington coast since 2004 as part of an effort to monitor for marine mammals within the boundaries of the proposed expansion area of the Quinault Underwater Tracking Range (QUTR). This effort was designed to allow for: 1) characterization of the vocalizations of species present in the area, 2) determination of the year-round seasonal presence of all marine mammal species, and 3) evaluation of the distribution of marine mammals near the Navy range. Small boat visual surveys were conducted in the range, resulting in sightings of a broad range of marine mammal species throughout the year. In addition, we have collaborated with the Olympic Coast National Marine Sanctuary and NOAA Northwest Science Center to conduct a visual and acoustic survey for cetaceans in Sanctuary waters, including overlap into the proposed Navy range expansion. Two High-frequency Acoustic Recording Packages (HARPs) have been deployed near the QUTR, one in deep water within Quinault Canyon and a second in inshore waters on the shelf near Cape Elizabeth. HARP data from this area provide information on the seasonal presence of a broad range of marine mammal species. Note that reporting on this Washington project has been divided into two phases, with all acoustic and visual survey results from 2004 through 2007 discussed in Oleson *et al.* (2009), with subsequent analyses presented here.

In 2008 we initiated a long-term acoustic monitoring study off the Kona coast of the Island of Hawaii in cooperation with regular visual surveys conducted in the region. This cooperation provides a unique opportunity to obtain high-frequency acoustic recordings of tropical odontocetes, including beaked whales, which may be used as reference recordings for future long-term monitoring efforts within the Hawaii Range Complex. The HARP also provides the first information on the seasonal occurrence of odontocetes in this region from long-term passive acoustic monitoring.

Visual Monitoring for Marine Mammals off Washington

Erin M. Oleson[1,2], John Calambokidis[3], Erin Falcone[3], Greg Schorr[3], and Annie Douglas[3]

[1]UCSD Scripps Institution of Oceanography
[2] NOAA-NMFS-Pacific Islands Fisheries Science Center
[3]Cascadia Research Collective

Project Background

In September 2003, the U.S. Navy proposed expansion of its Quinault Underwater Tracking Range (QUTR), part of the Northwest Range Complex (Federal Register, Vol. 68: 53599-53600, 11 September 2003), into offshore waters and south along the shelf off the Washington coast. In 2004, we initiated an acoustic and visual monitoring project off the Washington coast (Figure 1). Acoustic monitoring was conducted by Scripps Institution of Oceanography using High-frequency Acoustic Recording Packages (HARPs); visual surveys were conducted by Cascadia Research Collective using rigid hull inflatable boats (RHIBs). In July 2007 the Navy renewed its intent to issue an Environmental Impact Statement (EIS/OEIS) for the range expansion (Federal Register, Vol. 72: 41712, 31 July 2007). Our 2007 Annual Report (Oleson *et al.* 2009) compiled all of the project findings from 2004-2007 for inclusion into the EIS for the QUTR expansion, providing the multi-year and year-round visual and acoustic study for this region. Since that report, additional acoustic monitoring and visual surveys have been conducted. New data collected and analyses conducted since the 2007 Annual Report are included here.

Methods and Goals

Small boat visual surveys-- A 5.3 to 5.9 m RHIB was used to conduct surveys out of Grays Harbor, Washington. The goal was to conduct surveys during periods of good weather, with an emphasis on sampling as consistently as possible across different seasons through an entire year. Weather was monitored and surveys only attempted during periods of forecast good weather. Two to three people including the driver were aboard during each survey, and visual observations were maintained for marine mammals during the entire survey. Weather and time permitting, the surveys followed a similar route: 1) Grays Harbor to the Quinault Canyon, stopping at both of the HARP locations there; 2) Quinault Canyon south along deeper waters to Grays Canyon; and 3) Grays Canyon back to Grays Harbor. Slight variations to this route were made as necessitated by weather and time constraints and in response to sightings.

When marine mammals were encountered, we recorded the time, position, species, number of animals, behavior, environmental conditions, and water depth. For large cetacean sightings,

especially of humpback, gray, and killer whales, photographs were taken to document species and to allow photographic identification of individual animals. Photographic identification was conducted using methods established in past work along the west coast on gray whales (Calambokidis *et al.* 2004a) and humpback whales (Calambokidis & Barlow 2004, Calambokidis *et al.* 2004b). Biopsy samples were also collected from some of the whales encountered using a small dart fired from a crossbow.

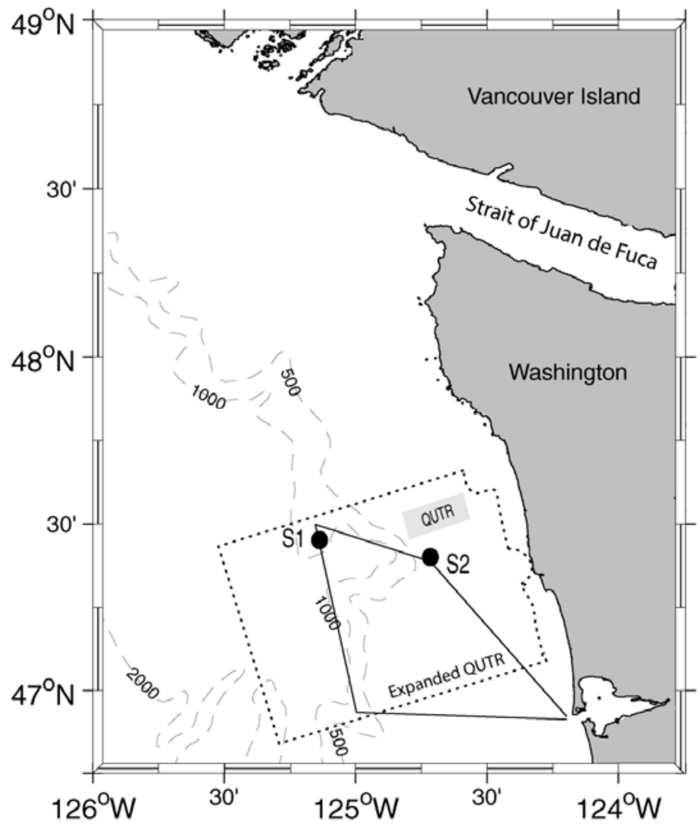


Figure 1: **Locations of two High-frequency Acoustic Recording Packages, S1 and S2, and the monthly visual survey track (solid line) in the QUTR region off the coast of Washington.**

Olympic Coast National Marine Sanctuary cetacean survey-- Joint visual-acoustic surveys were conducted in collaboration with the Olympic Coast National Marine Sanctuary (OCNMS) and the Northwest Fisheries Science Center in June 2008. Marine mammal sighting and effort data were collected from the flying bridge of the *NOAA Ship McArthur II* by an experienced observer using hand-held reticle binoculars. A second observer searched close to the ship and entered data into an event-driven data acquisition program called Wincruz. Position, time, and heading of the ship were downloaded automatically from the ship's GPS, and observation conditions were noted every half hour, or more frequently if necessary. At a minimum, sighting data collected included time, location of vessel, species, distance to animal, number of animals present (best/high/low), presence of calves, and whether photographs were obtained. Observers were considered to be "on effort" when the ship was transiting at 10 kts

in Beaufort 5 or less, and visibility was equal to or greater than 0.5 nmi. The fourteen OCNMS survey lines run east-west and follow the permanent tracklines established by the *NOAA Ship Miller Freeman* in 1989. The two northernmost lines extend into Canadian waters off Southern British Columbia (Vancouver Island). Photographs of all species encountered were obtained from either the *NOAA Ship McArthur II* or the ship's RHIB, which, when conditions and animal behavior seemed acceptable, was launched for photo identification (ID) of individual whales. Using the animal's naturally occurring pigmentation, photographic ID of humpback and killer whales has been utilized to investigate many aspects of these species. Coincident with visual observations, two acousticians monitored a towed hydrophone array for marine mammal vocalizations. When cetacean groups were heard, crossed-pair bearing was computed based on two sensors in the array, and a bearing estimate to the vocal group was produced. These surveys allowed for collection of acoustic data from visually identified species to aid in species-discrimination algorithms, and will serve to provide an opportunity to directly compare visual and acoustic detection rates for some species.

Project goals included:

1. Evaluate the presence of odontocete and mysticete cetaceans based on the presence of vocalizations near the existing Quinault Underwater Tracking Range (QUTR) and the region of the proposed range expansion.
2. Conduct regular visual observations for marine mammals within the expanded QUTR.
3. Determine the relative abundance of mysticete and odontocete cetaceans in this region using the combined visual and acoustic survey data sets.
4. Develop models of cetacean habitat using the visual and acoustic observations together with remotely sensed and mooring based oceanographic data.

Results

Small boat visual surveys

A total of 42 small boat surveys were conducted over a 5-year period between August 2004 and June 2009 representing 490 hours and 6484 nmi of survey effort. (For 2004 – 2008 surveys, see Appendix Table A-I.) Eight surveys were conducted during good weather windows from July 2008 to June 2009 (Table 1). Some survey routes had to be curtailed slightly due to weather or day length. Maps indicating the location of each dolphin and porpoise (Figure 2), whale (Figure 3), and pinniped (Figure 4) sighting are included. Since July 2008, a total of 64 sightings of 159 marine mammals were made during the small boat surveys (Table 2) representing 7 cetacean and 5 pinniped species. Overall, harbor porpoise were the most frequently sighted marine mammal (20 sightings), consistent with previous years of survey effort. Additionally, there were 8 sightings of 24 Dall's porpoise. The only other small cetacean seen in these recent surveys was a single sighting of Pacific white-sided dolphins. Among the large whales, both gray whales (8 sightings of 16 whales) and humpback whales (6 sightings of 10 whales) were the most common (Table 2). Sightings of gray whales occurred primarily in winter (during the southbound migration) and spring (during the northbound migration). No concentrations of feeding gray whales were seen in summer, as had occurred in summer 2007, when up to 30 gray whales were seen feeding well offshore but still on the shelf, as reported in

Oleson *et al.* (2009). Humpback whales were sighted in summer and early fall, although in past years this species has been seen in smaller numbers in winter. Sightings of humpback whales occurred in both near-shore waters on the continental shelf near the shelf edge and in deeper waters in Grays Canyon (Figure 3).

Table 1: Visual survey effort off the Washington coast, July 2008 to June 2009.

Date	Begin	End	Duration (Hrs)	Distance (nmi)
2-Jul-08	8:46	18:44	9.97	158
10-Aug-08	7:50	19:40	11.83	133
2-Sep-08	7:55	16:00	8.08	140
15-Oct-08	8:15	16:30	8.25	105
13-Jan-09	7:45	17:02	9.28	144
22-Jan-09	7:43	15:44	8.02	135
30-Apr-09	7:18	15:44	8.43	141
2-Jun-09	7:28	17:41	10.22	155

Table 2: Sighting summary for surveys conducted July 2008 to June 2009.

	# of Sightings	# of Animals
Baleen Whales		
Blue whale	1	1
Fin whale	1	3
Humpback whale	6	10
Gray whale	8	16
Unidentified whale	1	1
Small Odontocetes		
Harbor porpoise	20	42
Dall's porpoise	8	24
Pacific white-sided dolphin	1	35
Pinnipeds		
Harbor seal	2	3
Elephant seal	1	1
California sea lion	3	6
Northern fur seal	8	12
Steller sea lion	4	5
Grand Total	**64**	**159**

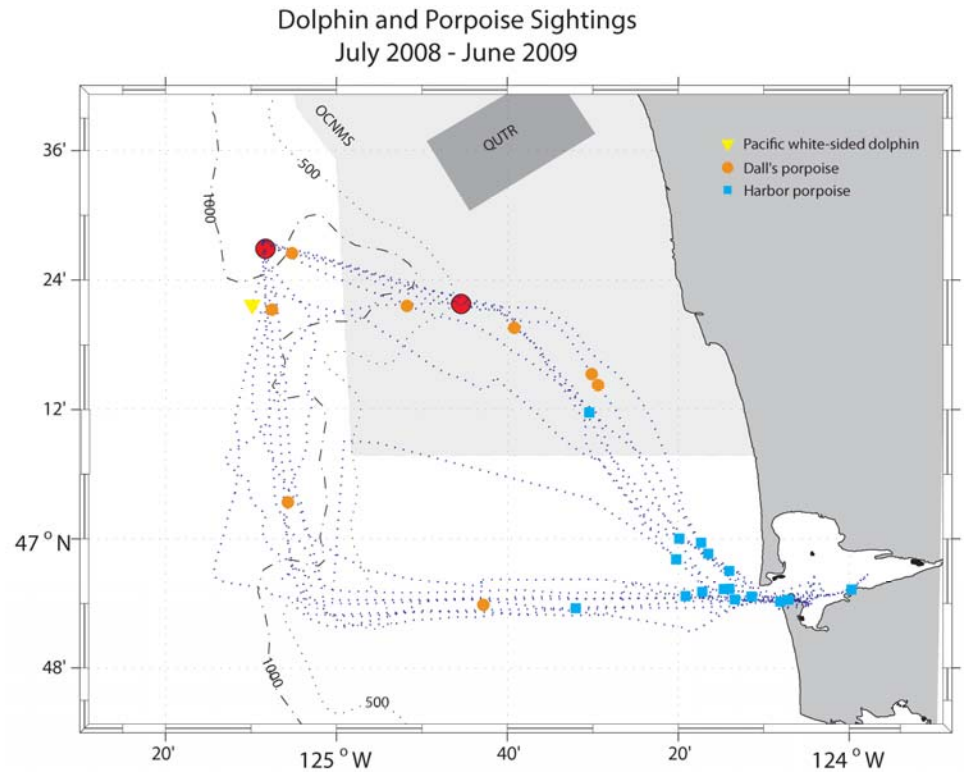


Figure 2: **Dolphin and porpoise sightings during visual surveys from July 2008 to June 2009. Sightings of Dall's and harbor porpoise are common in all months. HARP locations are designated by red dots.**

During the 13 January 2009 survey a blue whale and three fin whales were sighted in Grays Canyon (Figure 3). This is the first blue whale sighted in these surveys and the first confirmed sighting off Washington in several decades. Blue whales have been acoustically detected off Washington and been sighted both to the north and south of Washington, and some of these are known to have transited waters off Washington based on photo-ID matches, making a sighting not totally unexpected. The timing of this sighting in mid-winter was surprising, since many blue whales are known to have migrated to wintering areas off Mexico and Central America during this period. The presence of fin whales in the same area and the behavior of the animals were indicative of feeding. A follow-up survey two days after these sightings had to be aborted due to poor weather prior to reaching Grays Canyon, and neither species was sighted when a follow-up survey was possible 9 days after the initial sightings. No photo-ID match was found for this animal in a comparison with Cascadia Research Collective's catalog of close to 2000 blue whales from the eastern North Pacific.

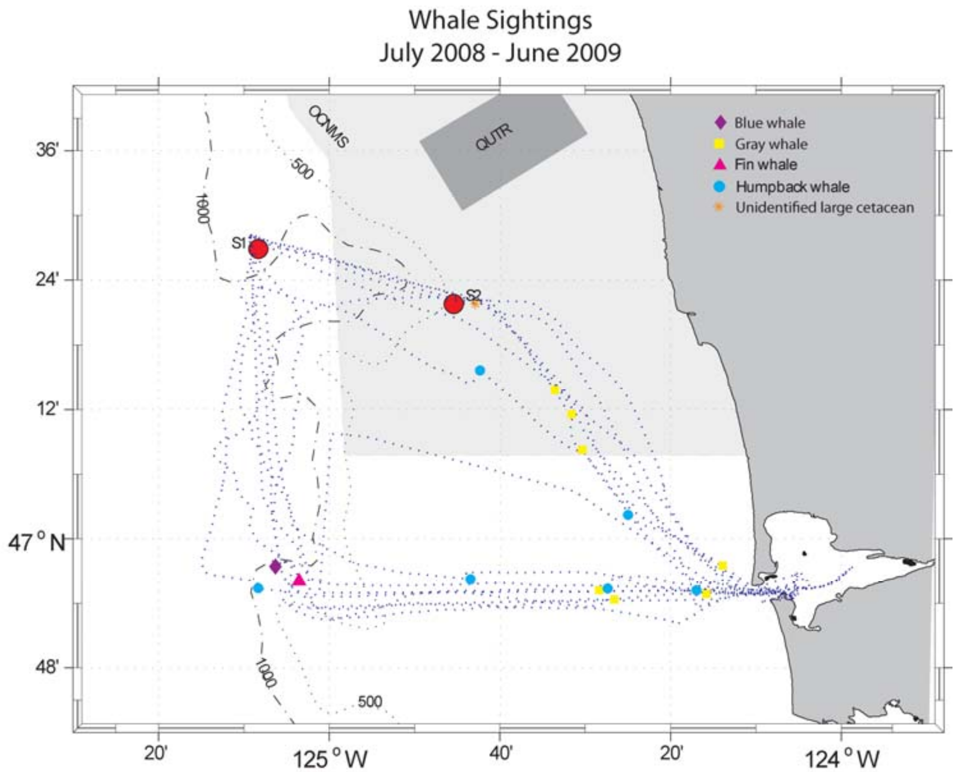
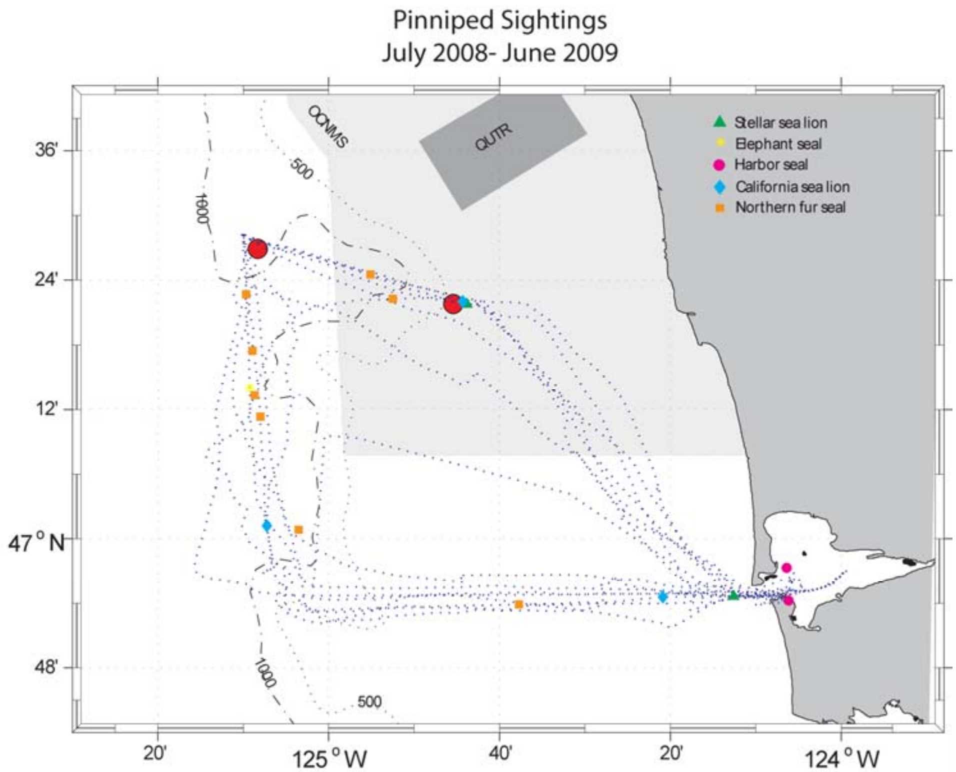


Figure 3: **Large whale sightings during visual surveys from July 2008 to June 2009. Humpback whales are the most common large whale, though Gray whales are also common in winter and spring. HARP locations are designated by red dots.**

Five pinniped species were seen in these recent surveys, including harbor seal, elephant seal, California sea lion, Steller sea lion, and northern fur seal. These were generally seen in very small numbers either in coastal or offshore waters, depending on the species.

Overall survey results from the last year were consistent with those from previous seasons, with the addition of a new species (blue whale) and improved sample sizes of other species. Habitat and seasonal differences in the occurrence of most marine mammal species were presented in Oleson *et al.* (2009).



<u>Figure 4:</u> Pinniped sightings during visual surveys from July 2008 to June 2009. Northern fur seals are the most commonly observed pinniped. HARP locations are designated by red dots.

Olympic Coast National Marine Sanctuary cetacean survey-- June 2008

Survey effort for marine mammals was conducted in the Olympic Coast National Marine Sanctuary 14-22 June 2008. All survey lines were completed (Figure 5), although not all lines were completed under acceptable conditions. All marine mammals encountered were identified to species when possible and best/high/low estimate of group size was made. There were 235 cetacean encounters of six species, and 21 pinniped or sea otter encounters of five species (Table 3). Humpback whales were the most frequently encountered cetacean species in the OCNMS (Figure 5 and Figure 6), followed by Dall's porpoise (Figure 5). Comparisons of individual whale photographs from two groups of killer whales sighted found matches with California transient killer whales (first sighting) and Alaska transient killer whales (second sighting). Pinniped and sea otter sightings are shown in Figure 7.

Table 3: Cetacean sightings from the survey conducted in the Olympic Coast National Marine Sanctuary and surrounding waters, 14-22 July 2008.

Species	***# Encounters On (Off) Effort***	***# Individuals On (Off) Effort***	***Estimated # Individuals Photographed***
Humpback whale	99 (45)	140 (104)	72
Gray whale	5 (3)	11(8)	1
Unidentified large whale	26 (4)	45 (7)	0
Killer whale	2 (0)	11 (0)	10
Pygmy sperm whale	1 (0)	1 (0)	NA
Dall's porpoise	29 (10)	129 (33)	NA
Harbor porpoise	5 (3)	40 (4)	NA
Unidentified dolphin	1 (1)	1 (6)	NA
Unidentified porpoise	1 (0)	1 (0)	NA
TOTAL	169 (66)	379 (162)	83

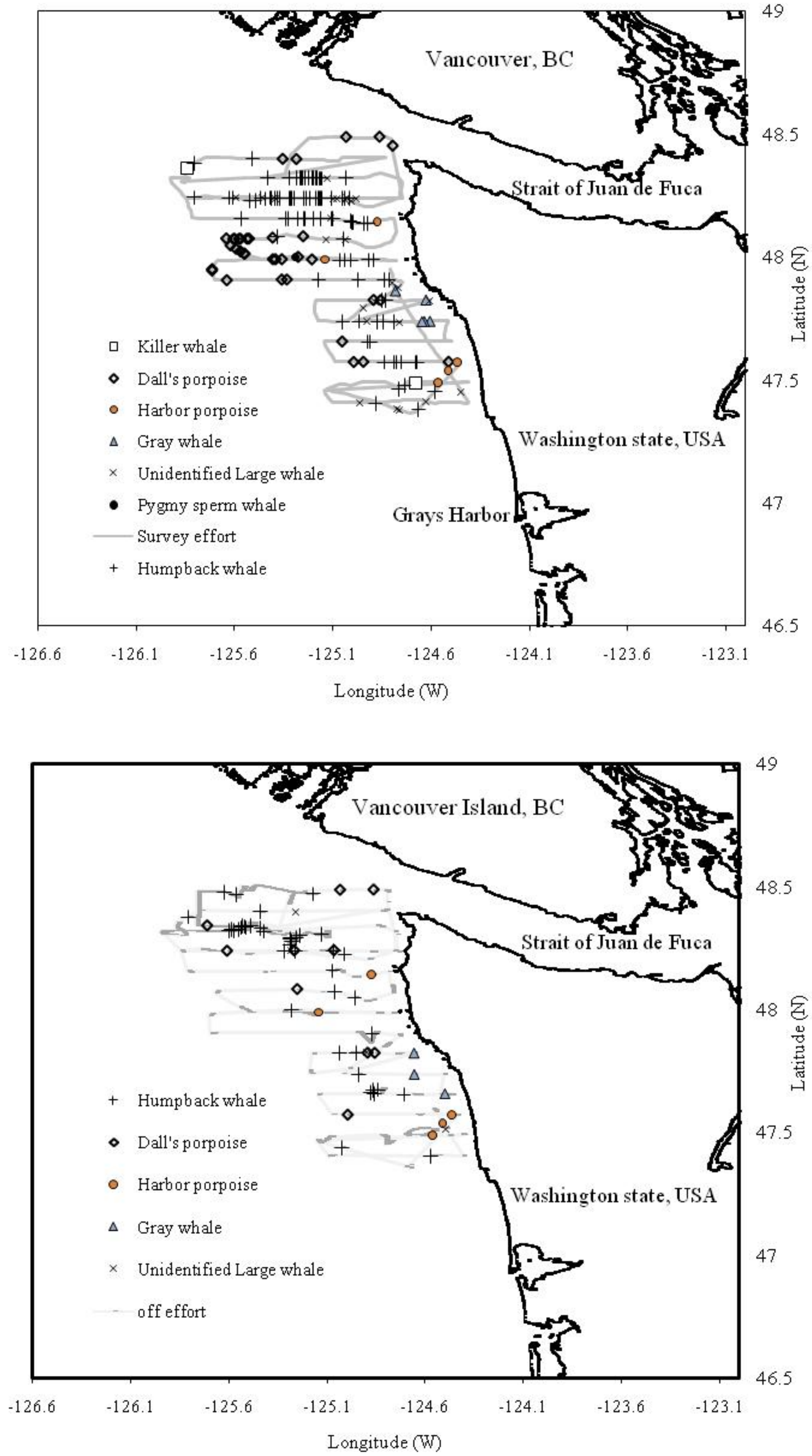
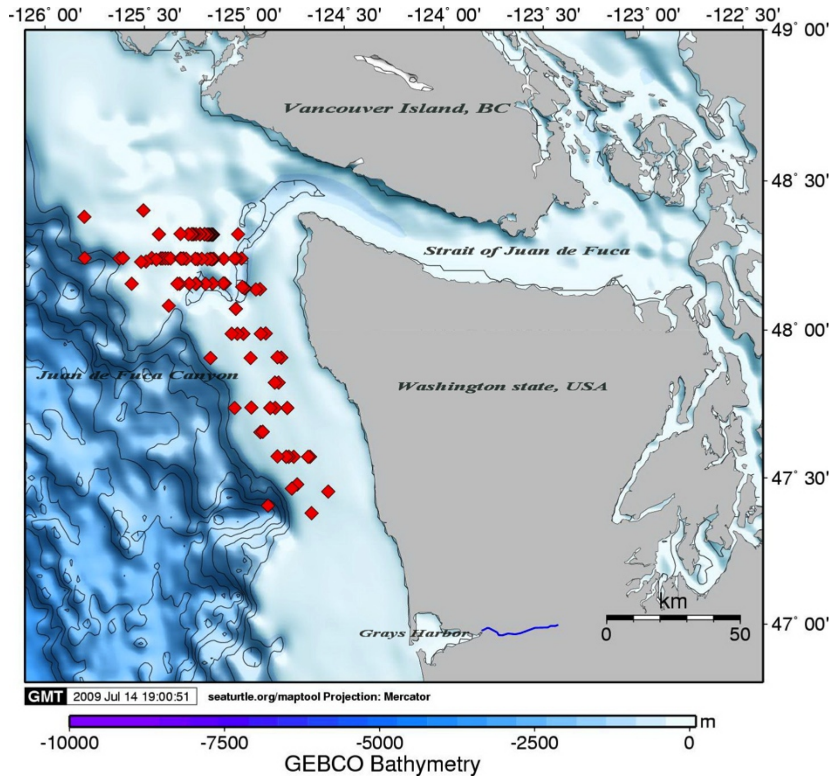


Figure 5: **On effort survey lines and on effort cetacean sightings (*upper panel*) and off effort survey lines and sightings (*lower panel*) in the Olympic Coast National Marine Sanctuary, 14-22 June 2008.**



<u>Figure 6:</u> Humpback sightings and the 250 meter contour line in the OCNMS and surrounding waters, 14-22 June 2008 marine mammal survey.

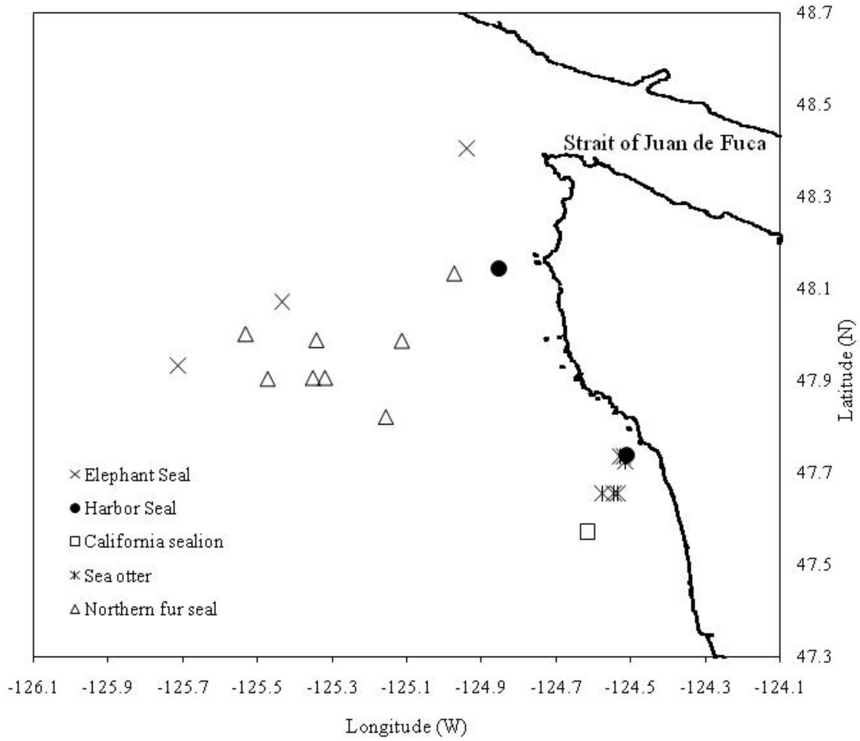


Figure 7: **Sighting map of pinniped and sea otter sightings from a marine mammal survey of the Olympic Coast National Marine Sanctuary and surrounding waters, 14-22 June 2008.**

Acoustic Monitoring for Marine Mammals off Washington

Ana Širović[1], Erin M. Oleson[2], John Calambokidis[3], Simone Baumann-Pickering[1], Amanda Cummins[1], Sara Kerosky[1], Lauren Roche[1], Anne Simonis[1], Sean M. Wiggins[1], and John A. Hildebrand[1]

[1] UCSD Scripps Institution of Oceanography;
[2] Pacific Islands Fisheries Science Center;
[3] Cascadia Research Collective

Project Background

The outer Washington coast of the United States is a productive marine ecosystem home to many species of marine mammals, including beaked whales, killer whales, and other cetaceans and pinnipeds. The U.S. Navy's Quinault Underwater Tracking Range (QUTR), part of the Northwest Training Range Complex, is located along the outer Washington coast and has been proposed for expansion into deep water habitats, used by beaked and sperm whales, and south along the shelf, where coastal cetaceans forage. In July 2004, an acoustic and visual monitoring effort was initiated to characterize the vocalizations of marine mammal species present in the area, to determine the year-round seasonal presence of all odontocete and mysticete whales, and to evaluate the distribution of cetaceans near the Navy range. Two High-frequency Acoustic Recording Packages (HARPs) have been deployed near the QUTR (Figure 1), one in deep water within Quinault Canyon (S1) and a second in inshore waters on the shelf (S2). In addition, visual surveys have been conducted on about a monthly basis in the region (Figure 1).

Methods

Acoustic data were collected at two sites using autonomous High-frequency Acoustic Recording Packages (HARPs) sampling at 200 kHz with 1/7 duty cycle (5 minutes of continuous data recording out of every 35-minute window) in the 2008/09 sampling season (Table 4). A feature of the data logging system resulted in an abandonment of the duty cycle on 1 January 2009 and produced continuous recordings for five days, after which the duty cycle resumed. The HARP deployed offshore during this period was lost. Thus data are available only for the inshore site, S2, between June 2008 and June 2009. Likewise, the HARP deployed inshore from December 2009 to January 2011 was lost, presumably due to the intense bottom trawling that occurs in this area. We continued acoustic data collection at the offshore site in January 2011 and at the inshore site in May 2011.

<u>Table 4:</u> Acoustic data collection near QUTR since July 2004. Period of instrument deployment analyzed in this report is shown in bold. Results of acoustic monitoring through June 2008 are described in Oleson *et al.* (2009).

Acoustic Monitoring Period	Sample Rate & Duty Cycle (on duration and interval between recordings, in min.)	S1: Offshore	S2: Inshore
OCNMS01: July – October 2004	80 kHz continuous	Yes	Lost
OCNMS02: October 2004 – July 2005	80 kHz 10/20	Data ended 1/05	
OCNMS03: July 2005 – August 2006	80 kHz 6/12	Data ended 2/06	
OCNMS04: August 2006 – March 2007	80 kHz 6/12	Data ended 2/07	Yes
OCNMS05: April – July 2007	80 kHz continuous	Yes	Yes
OCNMS06: July 2007 – June 2008	200 kHz 5/35	Yes	
OCNMS07: October 2007 – June 2008	200 kHz 5/30		Yes
OCNMS08: June 2008 – June 2009	**200 kHz 5/35**	**Lost**	**Yes**
OCNMS09: December 2009 – January 2011	**200 kHz 5/30**		**Lost**
OCNMS10: January 2011 – December 2011	200 kHz continuous	Yes	
OCNMS10: May 2011 – December 2011	200 kHz continuous		Yes

Acoustic Data Analysis

The daily presence of acoustic signals from multiple marine mammal species including blue whales (*Balaenoptera musculus*), fin whales (*B. physalus*), gray whales (*Eschrichtius robustus*), humpback whales (*Megaptera novaeangliae*), sperm whales (*Physeter macrocephalus*), killer whales (*Orcinus orca*), Risso's dolphins (*Grampus griseus*), and Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) was analyzed. Pinniped and likely porpoise sounds were also identified in the data, as was the daily presence of anthropogenic noise such as U.S. Navy sonar, explosions, and shipping. All data were analyzed by visually scrutinizing long-term spectral averages (LTSAs) in appropriate frequency bands. When a sound of interest was identified in the LTSA, examining the waveform or spectrogram at the time of interest was possible to identify particular sounds to species or source, as necessary. Acoustic classification was carried out either from comparison to species-specific spectral characteristics or through analysis of the time and frequency characters of individual sounds.

For efficient analysis, data were divided into three frequency bands and each band was analyzed for the sounds of an appropriate subset of species or sources. Blue, fin, and gray whale sounds

were classified under low-frequency (below 1 kHz); killer and sperm whales, pinnipeds, shipping, explosions, and sonar were classified under mid-frequency (up to 5 kHz); while the remaining odontocete sounds were considered high-frequency (above 10 kHz). For the analysis of the mid-frequency recordings, data were decimated by a factor of 20, while for the low-frequency analysis, they were decimated by a factor of 100. The LTSAs were created using a 5-s time average with 200 Hz resolution for high-frequency, 10 Hz resolution for mid-frequency, and 1 Hz resolution for low-frequency data analysis.

In this report, we summarize acoustic data collected from June 2008 until June 2009 since the last comprehensive report (Oleson *et al.* 2009). We discuss seasonal occurrence and relative abundance of species that can be consistently identified in the acoustic data in the context of earlier visual and acoustic data collections, as well as the visual observations conducted during the same period.

Results

Cetacean species detected in the acoustic data set between June 2008 and June 2009 at the S2 site include: blue whales, fin whales, gray whales, humpback whales, sperm whales, killer whales, and Risso's dolphins. Also, a number of sounds that were detected have not yet been classified to species, but they include likely porpoise clicks, a variety of dolphin signals, and pinniped calls. Details of species-specific trends in acoustic activity are described below.

Findings by Species

Blue Whales

Three different calls were used to identify the presence of blue whales in the dataset. Calls of type A and B (Figure 8) are representative of the blue whale population found in the eastern North Pacific (McDonald *et al.* 2006) and are likely associated with mating behavior (Oleson *et al.* 2007a). D calls (Figure 9) are similar worldwide and are associated with feeding animals (Oleson *et al.* 2007b).

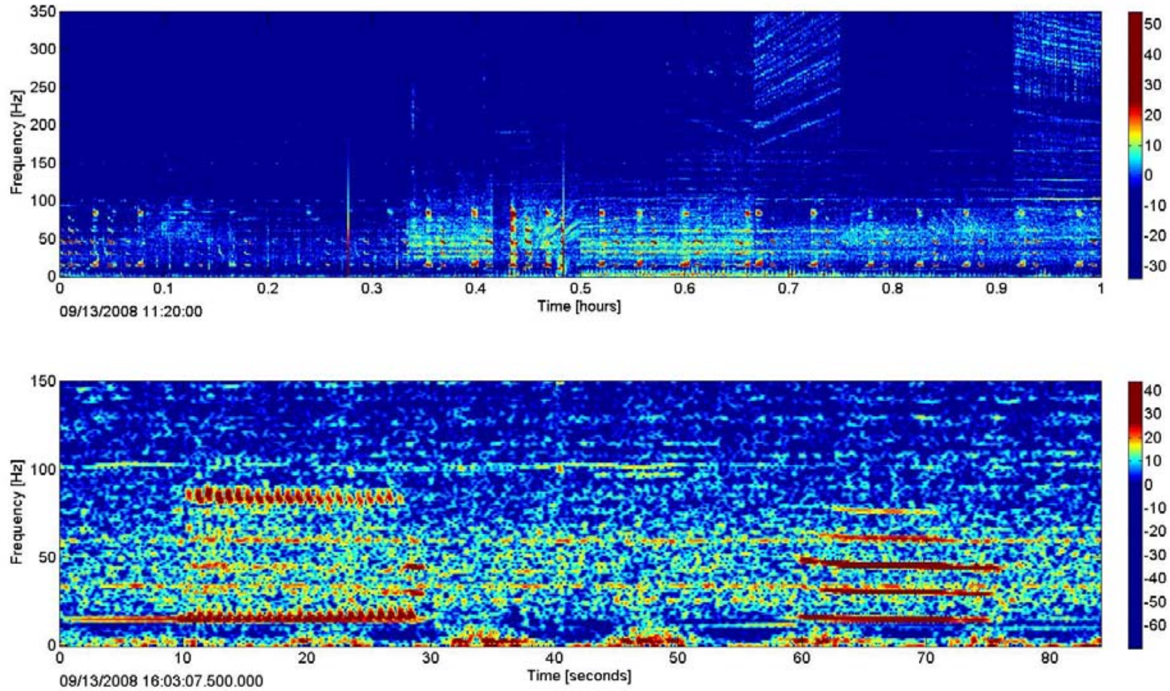


Figure 8: **Long term spectral average (*above*) and spectrogram (*below*) of blue whale A and B calls recorded at the inshore site in September 2008. (Spectrogram made with 1500-point FFT and 90% overlap.)**

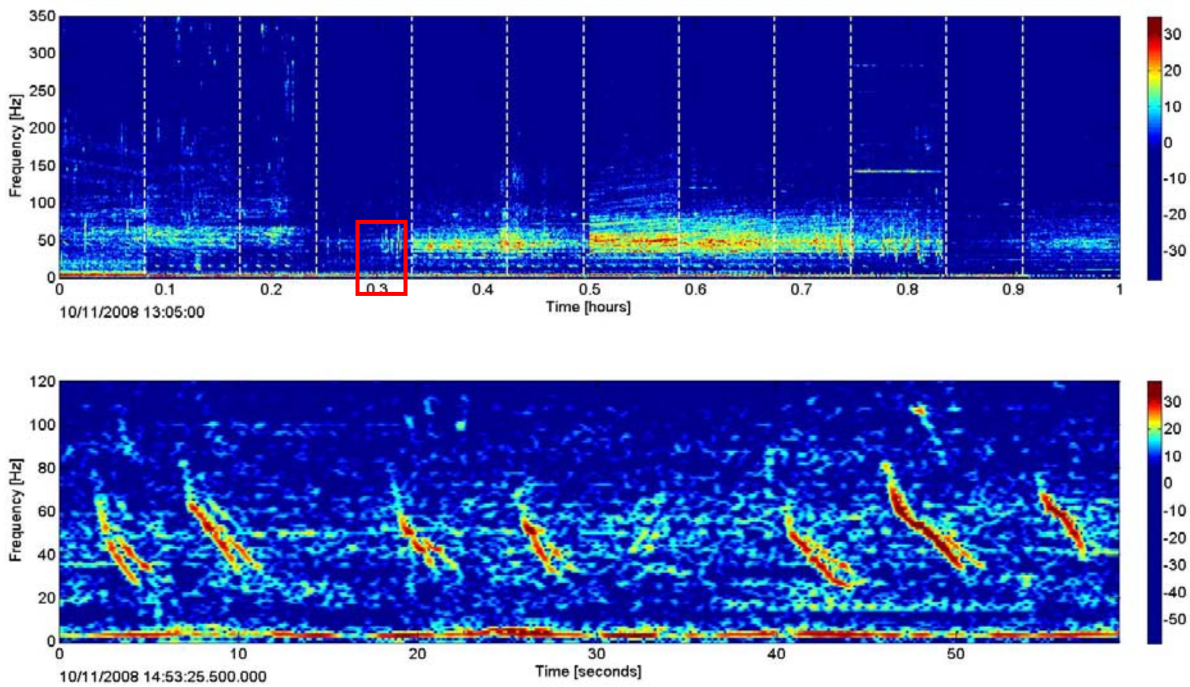
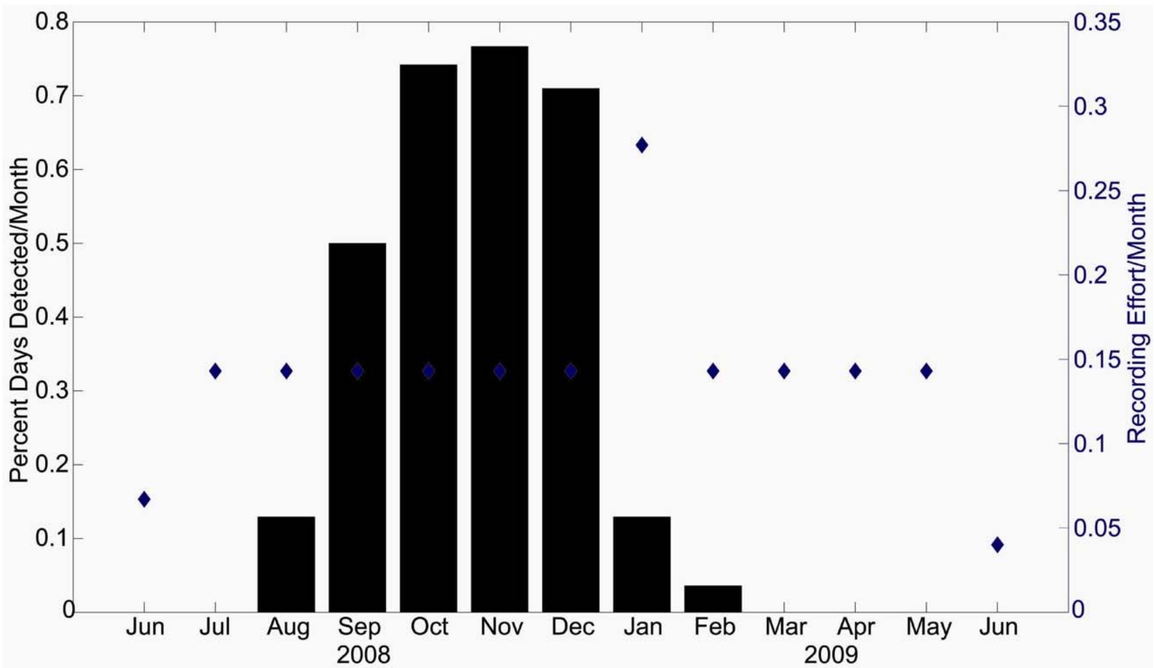


Figure 9: **LTSA (*above*) with a red box marking the period of blue whale D calls enlarged in the spectrogram (*below*), recorded at the inshore site in October 2008. (Spectrogram made with 1500-point FFT and 90% overlap.)**

Blue whale calls were detected at the inshore site between August 2008 and February 2009, with peak calling from October to December (Figure 10). This seasonal presence is consistent with seasonal occurrence of blue whale calls off Washington as reported by Watkins *et al.* (2000) and Burtenshaw *et al.* (2004). Blue whales are not frequently sighted at this location, but the first sighting in decades was reported by visual surveys during this monitoring period (Table 2).



<u>Figure 10:</u> Occurrence of blue whale A, B and D calls between June 2008 and June 2009 recorded at the inshore site. Black bars represent the fraction of days blue whales were detected in a month, and blue diamonds represent monthly recording effort. Recording effort of approximately 0.15 months is indicative of 1/7 duty cycle. More effort in January reflects the transition to continuous recording for 5 days. Less effort in June 2008 and June 2009 indicates that the instrument was deployed and recovered during these months.

Fin Whales

The occurrence of 20 Hz pulses (Figure 11) was used as an indication of fin whale presence in this dataset. Fin whale calls were most commonly detected between September and April (Figure 12). They were among the most commonly recorded calls and were detected on more than 90% of days during four months (October, December, January, and February), but they were absent from the data during May and June. These findings are also consistent with earlier acoustic surveys for fin whales conducted farther offshore (Watkins *et al.* 2000).

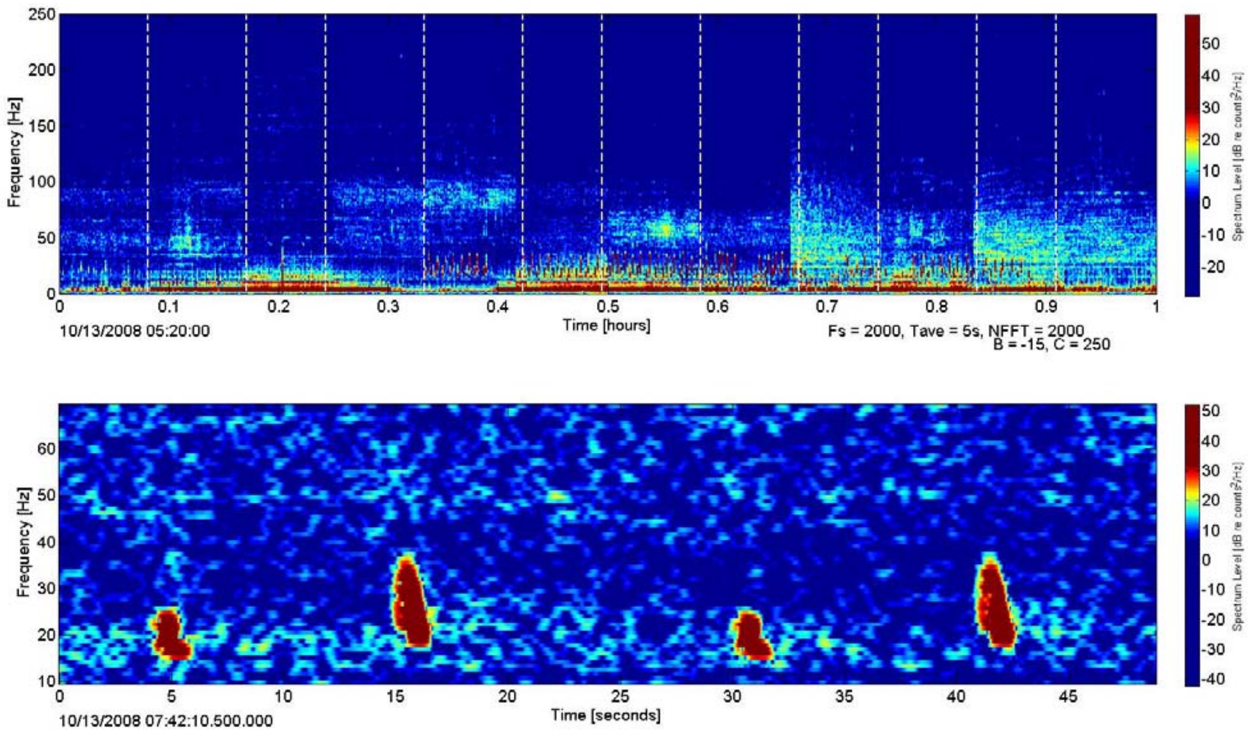


Figure 11: **LTSA (*above*) and spectrogram (*below*) of fin whale 20 Hz calls recorded at the inshore site in October 2008. (Spectrogram made with 3000-point FFT and 98% overlap.)**

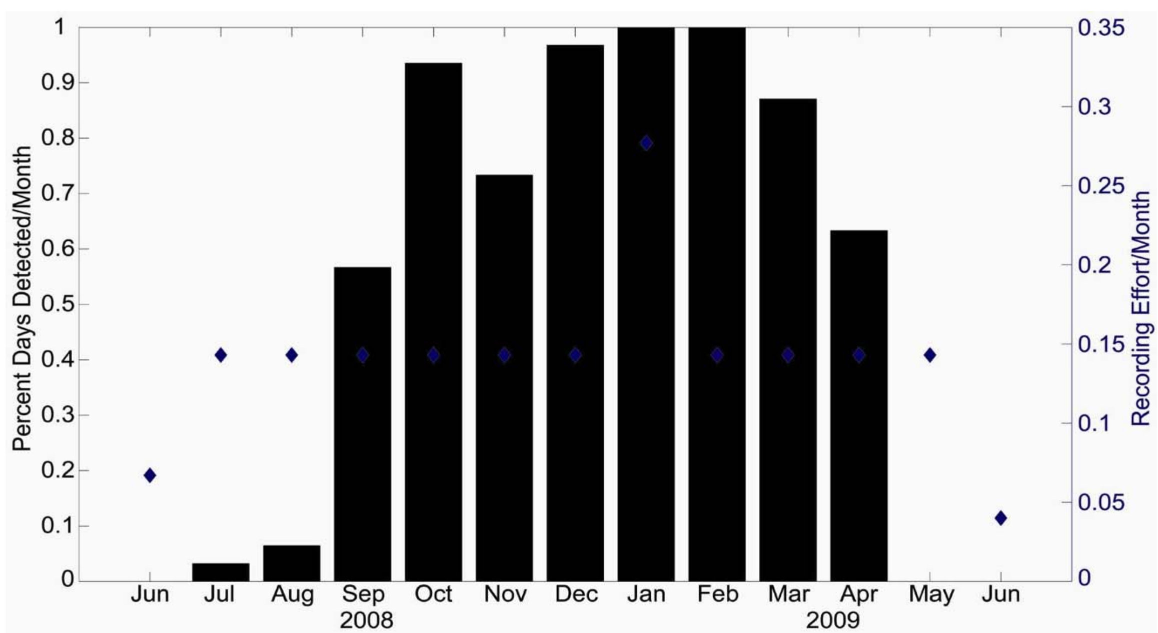


Figure 12: **Occurrence of fin whale calls between June 2008 and June 2009 recorded at the inshore site. Black bars represent the fraction of days fin whales were detected in a month and blue diamonds represent monthly recording effort.**

Humpback Whales

Energy in most humpback whale calls is centered between 100 and 3000 Hz. Humpback whale song (Figure 13) is categorized by the repetition of units, phrases, and themes (Payne & McVay 1971). Non-song vocalizations such as social sounds and feeding sounds consist of short duration (0.15 to 2.5 seconds long) individual units (Dunlop *et al.* 2007, Stimpert *et al.* 2011). Presence of both song and non-song vocalizations was analyzed in the acoustic data.

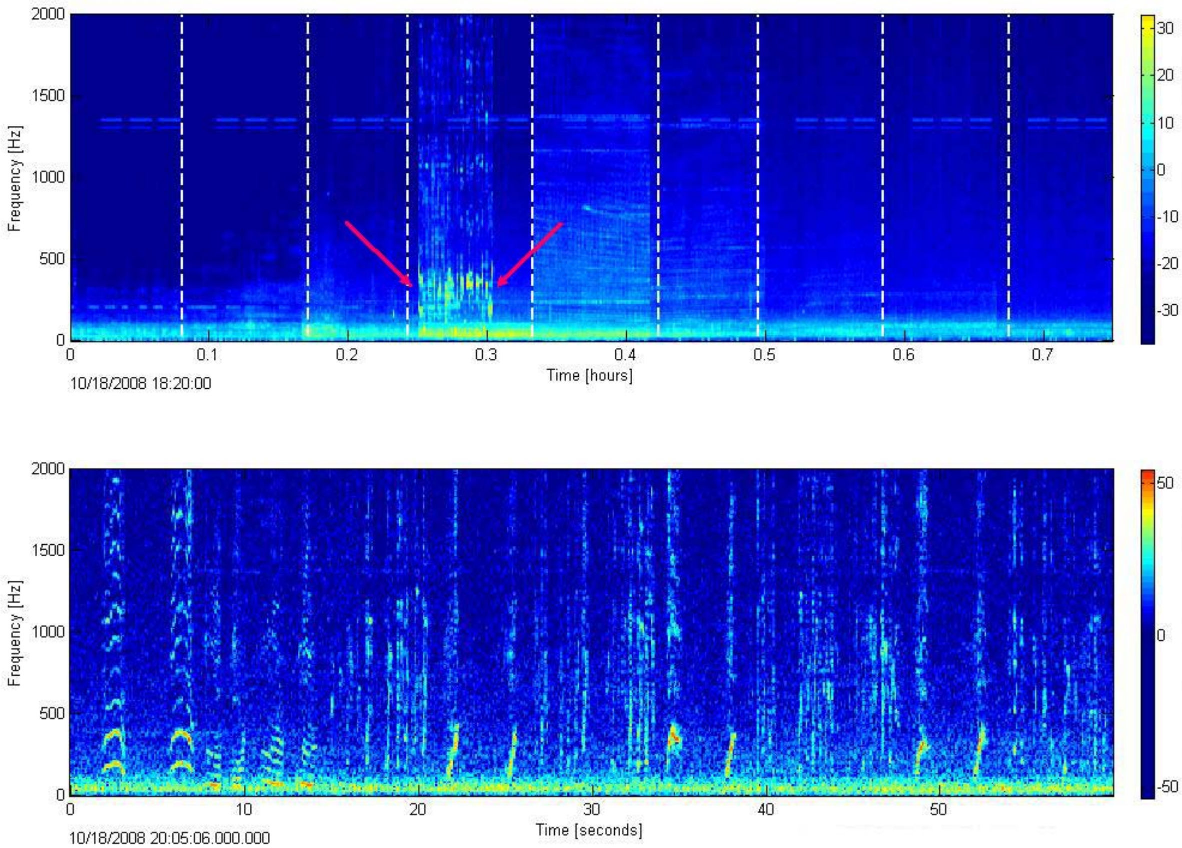


Figure 13: **LTSA (*above*) and spectrogram (*below*) of humpback whale song recorded at the inshore site in October 2008. White broken lines on the LTSAs denote start and end of each duty cycle, and red arrows point to the section of data containing humpback song (as shown in the spectrogram). Note that in this example, the song was recorded only during a single duty cycle.**

Consistent with previous recordings at this site, humpback whales were most commonly detected in the acoustic recordings between September and December (Figure 14), which was also the peak time for humpback singing (Figure 15). The lower level of calling from February through May is also consistent with previous years' findings (Oleson *et al.* 2009). Our record continues to show over-wintering presence of humpback whales in higher latitudes (Shelden *et al.* 2000). Visual and acoustic detections of humpback whales in this area do not fully overlap, as most visual sightings occur during the summer and early fall (Oleson *et al.* 2009), which is likely the result of the strong seasonal variation in humpback whale singing and other vocal behavior.

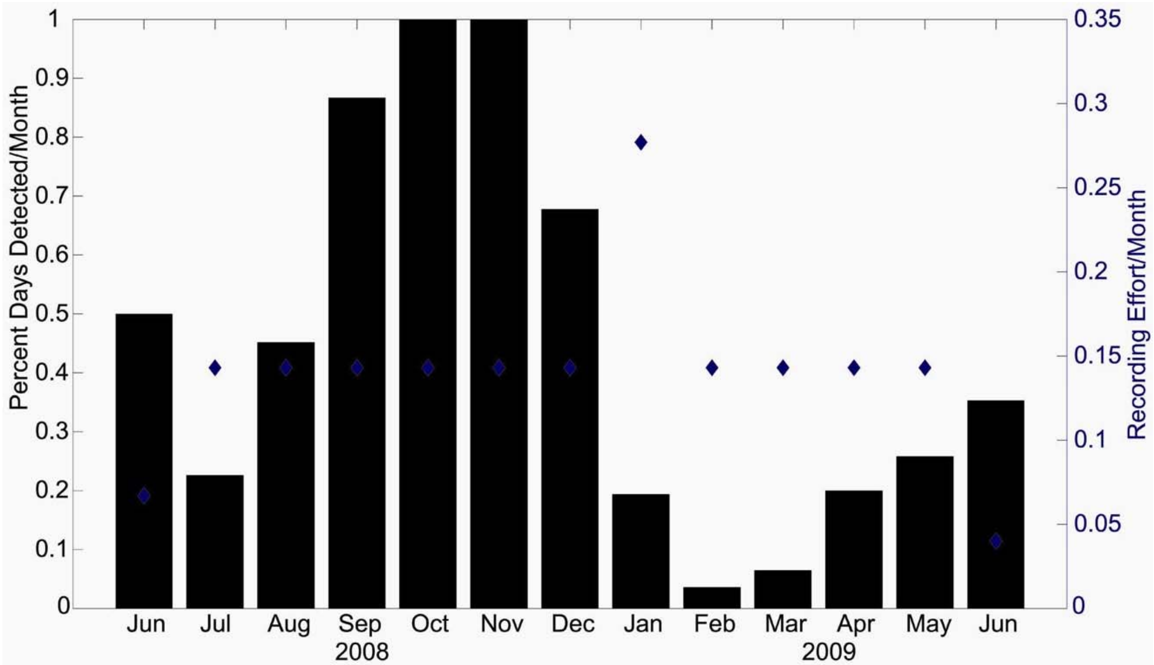


Figure 14: **Occurrence of humpback whale sounds (song and non-song) between June 2008 and June 2009 recorded at the inshore site. Black bars represent the fraction of days humpback whales were detected in a month and blue diamonds represent monthly recording effort.**

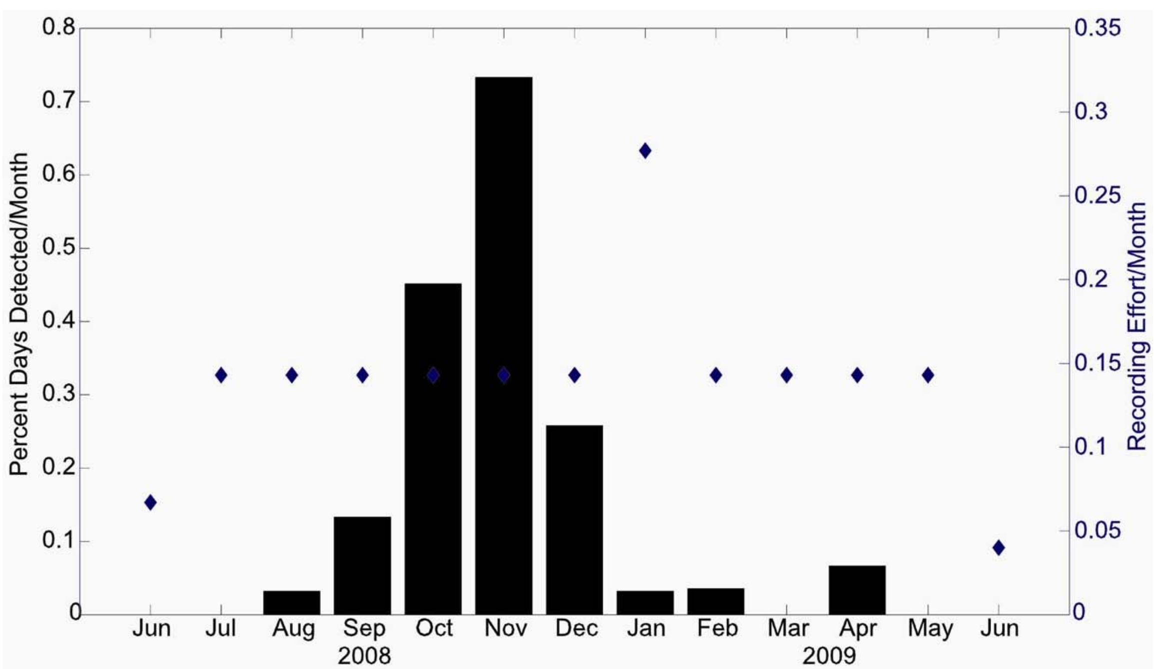


Figure 15: **Occurrence of humpback whale song only between June 2008 and June 2009 recorded at the inshore site. Black bars represent the fraction of days humpback whales were detected in a month and blue diamonds represent monthly recording effort.**

Gray Whales

While gray whale calls were often difficult to distinguish among humpback whale calls, the gray whale M3 call type, a short-duration, low-frequency moan (Crane & Lashkari 1996), could be most reliably detected in the data and thus was used as a proxy for gray whale presence at site S2 (Figure 16). Gray whale M3 calls were detected almost year-round (Figure 17), but at variable numbers, which are likely indicative of different stocks or different life stages. The majority of calling occurred from December through February, which corresponds to the timing of the southbound gray whale migration from the feeding grounds in Bering and Chukchi Seas to the breeding grounds off Baja California, Mexico. While the whales generally follow a path farther offshore during this migration, they could still be heard at the inshore site. Lower levels of calling until April could be reflecting the fact that gray whales are thought to be less vocal on the northbound migration, presumably trying to avoid detection by killer whales. Higher call rates in the summer likely represent the resident population that feeds in the northeast Pacific during this period. No large aggregations of feeding gray whales, however, were observed by the visual surveys during the summer (Oleson *et al.* 2009).

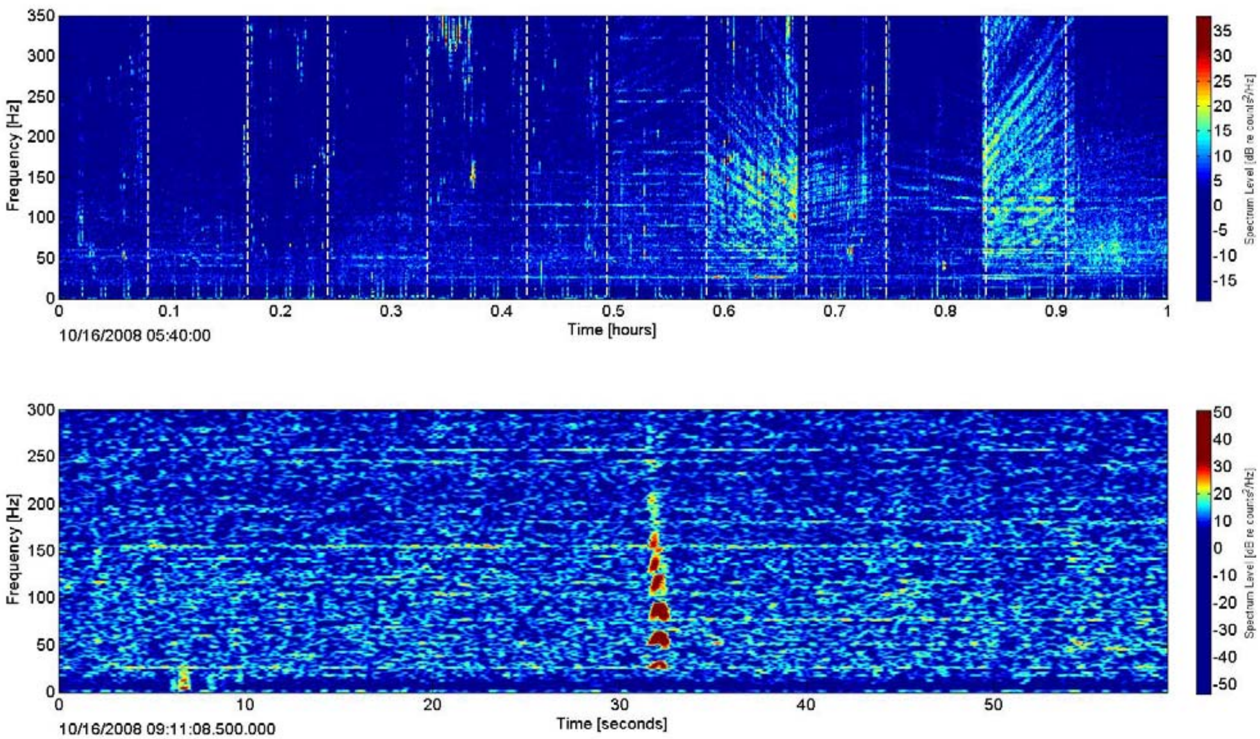


Figure 16: LTSA (*above*) and spectrogram (*below*) of gray whale M3 call type recorded at the inshore site in October 2008. (Spectrogram was made with 1500-point FFT and 98% overlap.)

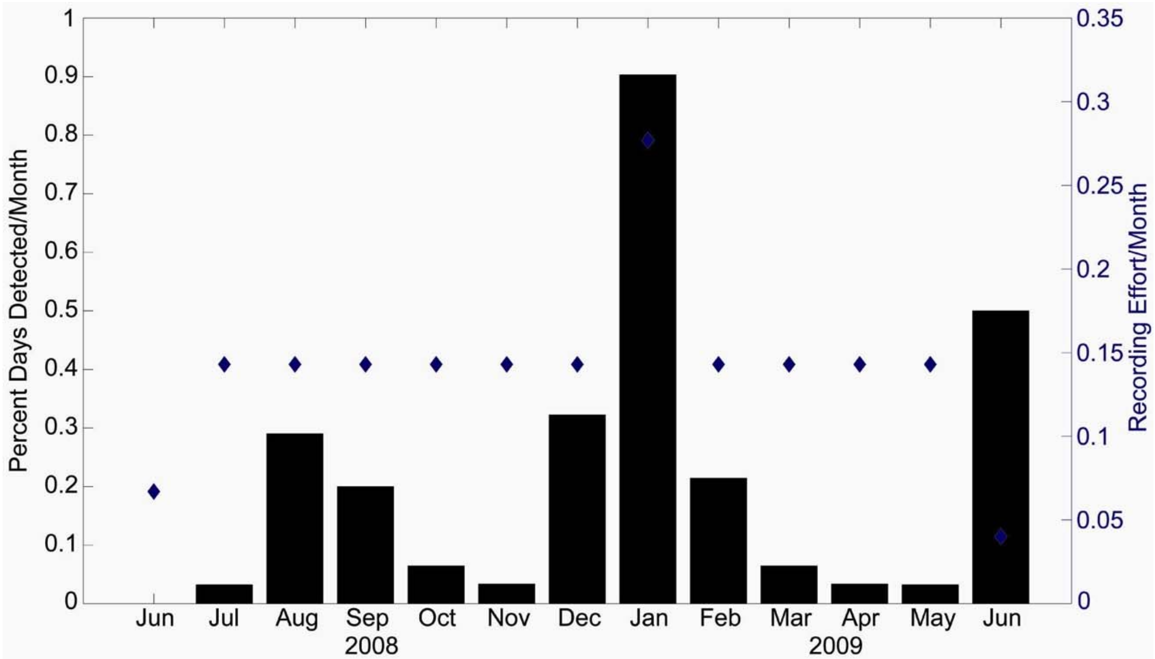


Figure 17: **Occurrence of gray whale M3 call type between June 2008 and June 2009 recorded at the inshore site. Black bars represent the fraction of days gray whales were detected in a month and blue diamonds represent monthly recording effort.**

Sperm Whales

Sperm whale clicks generally contain energy that extends from 2-20 kHz, with the majority of energy between 10-15 kHz and spectral peaks around 12 kHz (Mohl *et al.* 2003). Sperm whale clicks were detected through most of the year at the inshore monitoring site, although there was a notable absence of clicks between February and May 2009 (Figure 18). In previous years, sperm whales were detected at this location generally from April to November (Oleson *et al.* 2009). Their presence later in the year, and appearance in 2009 later than usual, could be an indicator of differing environmental conditions in 2008/09 in comparison to prior years of monitoring. As in previous years, there was a somewhat higher rate of click detections during nighttime at this location than during the day (Figure 19). No sperm whales were seen during visual surveys conducted during this acoustic monitoring period (Table 2).

Beaked Whales

No beaked whales were detected in this data set, which is not surprising considering that the location of the inshore recorder is in shallower water than is known to be beaked whale habitat. Likewise, no beaked whales were sighted during visual surveys conducted from June 2008 until June 2009 (Table 2).

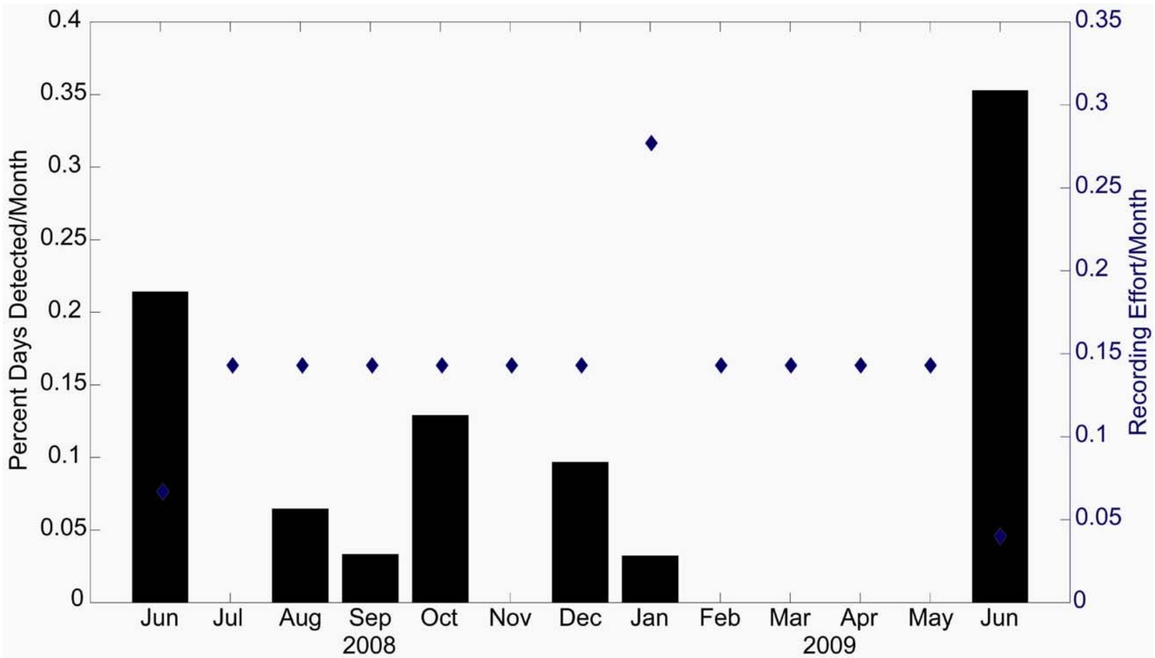


Figure 18: **Occurrence of sperm whale clicks between June 2008 and June 2009 recorded at the inshore site. Black bars represent the fraction of days sperm whales were detected in a month and blue diamonds represent monthly recording effort.**

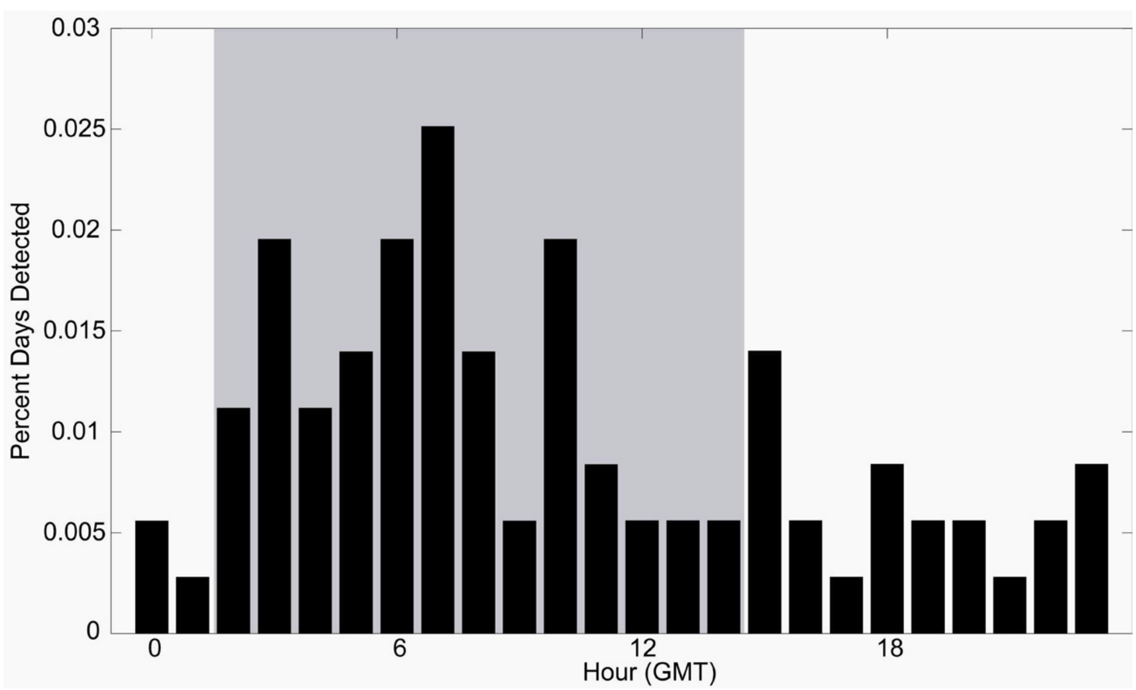


Figure 19: **Occurrence of sperm whale clicks between June 2008 and June 2009 by hour of the day. Shaded grey area represents average night period at this location through the year.**

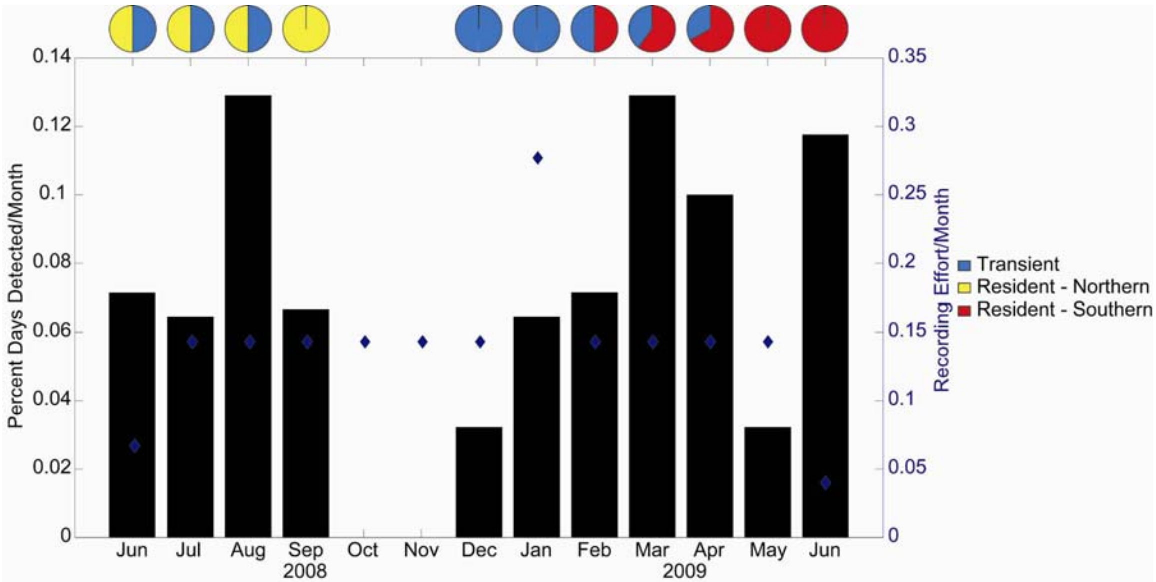


Figure 20: **Occurrence of killer whale ecotypes between June 2008 and June 2009 recorded at the inshore site. Black bars represent the fraction of days killer whales were detected in a month and blue diamonds represent monthly recording effort. The pie charts above the panel indicate relative occurrence of each killer whale ecotype during each month. Identification of killer whale call ecotypes courtesy of Amalis Riera, University of Victoria, and John K. B. Ford, University of British Columbia.**

Killer Whales

Three distinct killer whale ecotypes were detected acoustically, including Northern and Southern Residents and Transients (Figure 20). All Northern Resident killer whales belonged to clan G, while Southern Residents were from clans K, J, and L. Both the California and British Columbia transient killer whale dialects were detected. There was no overlap in seasonal presence of the two different Resident ecotypes. Northern Resident killer whales were detected generally in the summer of 2008, while Southern Residents were detected during the late winter through early summer of 2009. Both Resident ecotypes were previously detected in the area during the same months of the year (Oleson *et al.* 2009); so the temporal separation observed during this year may not be a persistent pattern. Transients, on the other hand, overlapped with both resident ecotypes, as they did in earlier years of surveys. No killer whales were sighted in visual surveys during this period (Table 2).

Pacific White-sided Dolphins

In a notable contrast to findings from previous monitoring, there was a conspicuous lack of Pacific white-sided dolphins in the acoustic data collected from June 2008 until June 2009. In previous years, Pacific white-sided dolphins were the most commonly detected odontocete in the acoustic dataset and they were heard for nine to ten months each year, albeit more commonly offshore (Oleson *et al.* 2009). Only one group of Pacific white-sided dolphins was sighted during the visual surveys conducted over this time period, and they were farther offshore than our recorder. This absence of Pacific white-sided dolphins from the area from June 2008 until

June 2009 may be an indication of a change in oceanographic conditions that may drive the dolphins' spatial distribution. Further investigation of the variation in environmental conditions among different survey years would help shed a light on this difference in Pacific white-sided dolphin presence in the survey area.

Risso's Dolphins

Risso's dolphin echolocation clicks are broadband impulses with the majority of energy between 20 and 60 kHz (Figure 21) and can be identified to species by their distinctive banding patterns observable in the LTSA, with energy peaks at 22, 26, 30, and 39 kHz (Soldevilla *et al.* 2008). Acoustic detections of Risso's dolphins during this study occurred between August and March (Figure 22) and they were detected more commonly than in previous years of monitoring in this area. Risso's dolphins, however, were not observed during the June 2008 to June 2009 visual surveys and, generally, are sighted infrequently during recent surveys (Oleson *et al.* 2009). They were, however, the most commonly sighted odontocete within the study area during aerial surveys in the late 1980s (Green *et al.* 1992).

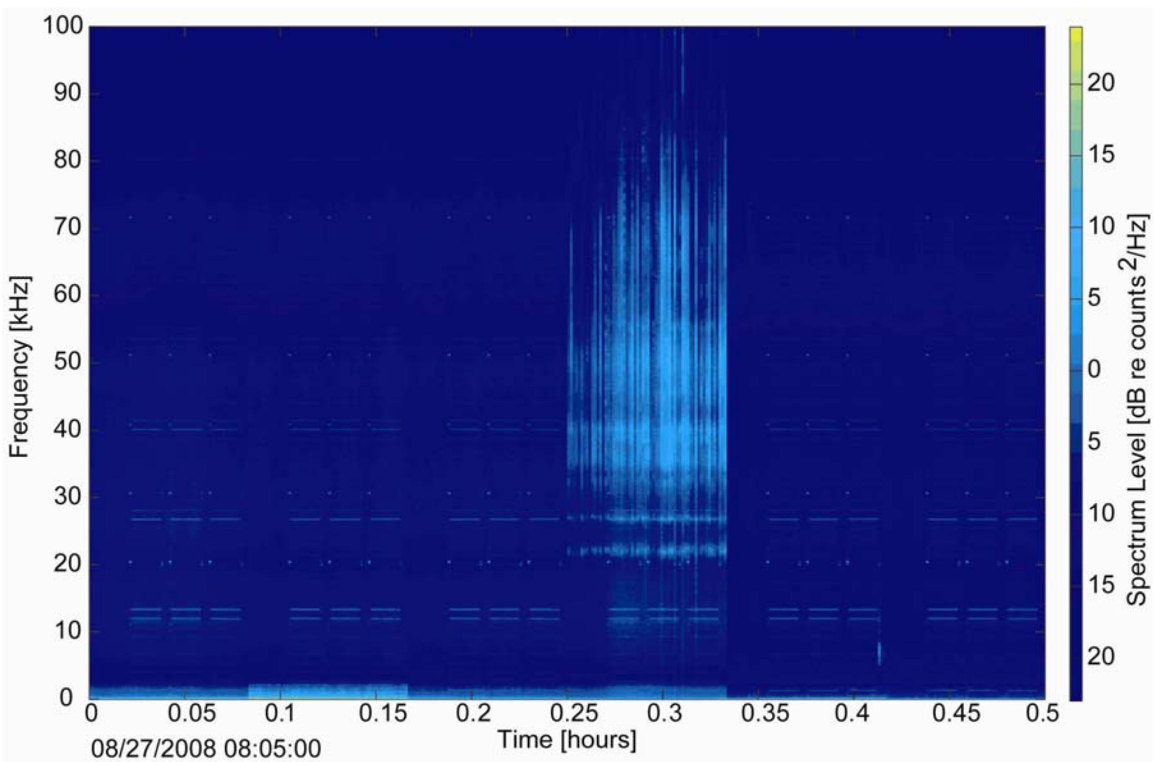


Figure 21: **LTSA of Risso's dolphin echolocation clicks recorded at the inshore site in August 2008. Note the characteristic spectral banding.**

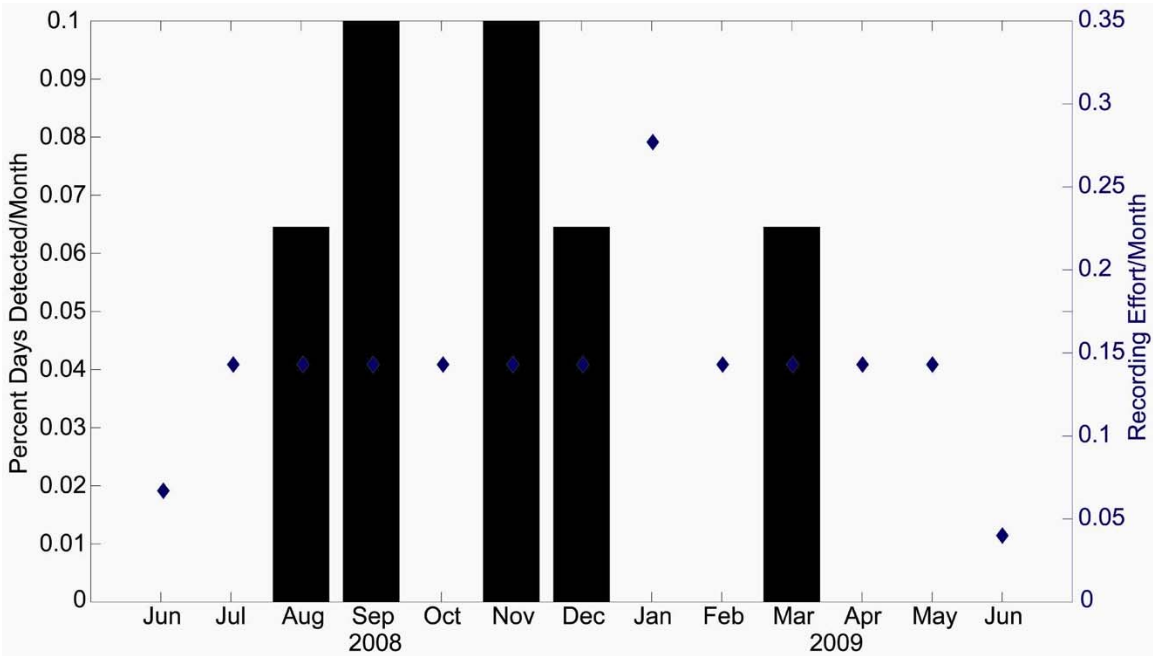


Figure 22: **Occurrence of Risso's dolphin echolocation clicks between June 2008 and June 2009 recorded at the inshore site. Black bars represent the fraction of days Risso's dolphin clicks were detected in a month and blue diamonds represent monthly recording effort.**

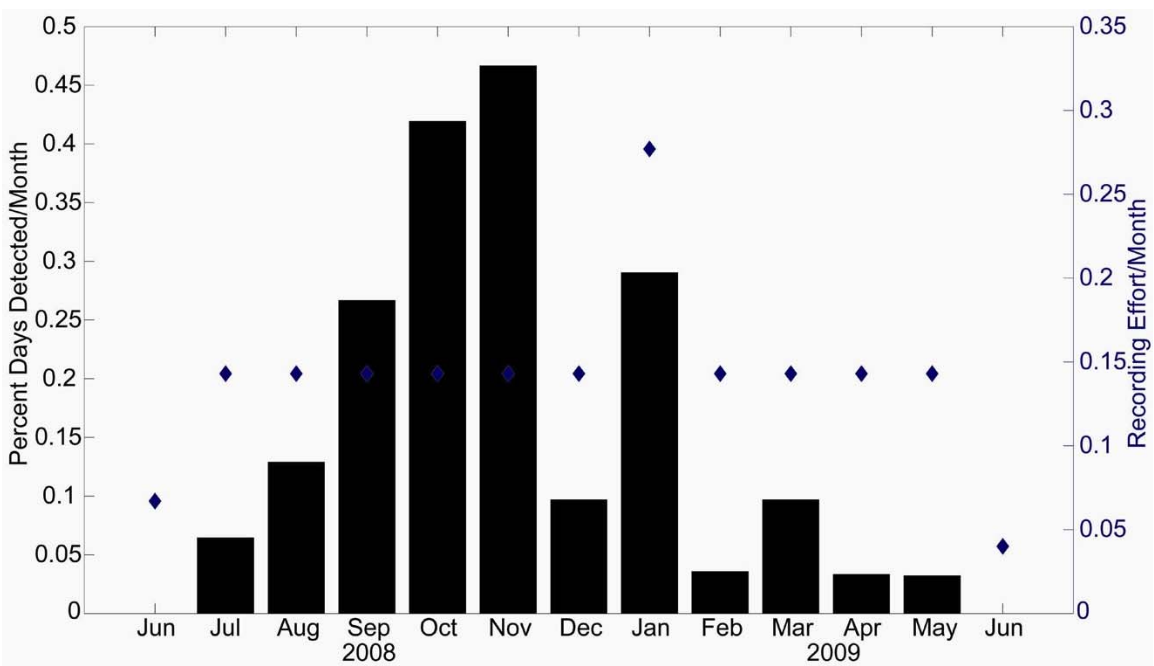


Figure 23: **Occurrence of whistles, burst-pulses, and echolocation clicks from unidentified odontocetes between June 2008 and June 2009 recorded at the inshore monitoring site. Black bars represent the fraction of days unidentified odontocete sounds were detected in a month and blue diamonds represent monthly recording effort.**

Unidentified Odontocetes

A large number of whistles, burst-pulses, and echolocation clicks have been detected that currently cannot be identified to species. Delphinid species thought to occur here, but whose sounds repertoire is not fully described, include northern right whale dolphin (*Lissodelphis borealis*), short-beaked common dolphin (*Delphinus delphis*), false killer whales (*Pseudorca crassidens*), and pygmy (*Kogia breviceps*) and dwarf sperm whales (*K. sima*). These sounds that cannot be identified to species were most common in the late summer and through the start of winter, and they are rare in the spring (Figure 23). Generally, whistles, burst-pulses and echolocation clicks recorded from unknown odontocetes were detected more commonly at night (Figure 24).

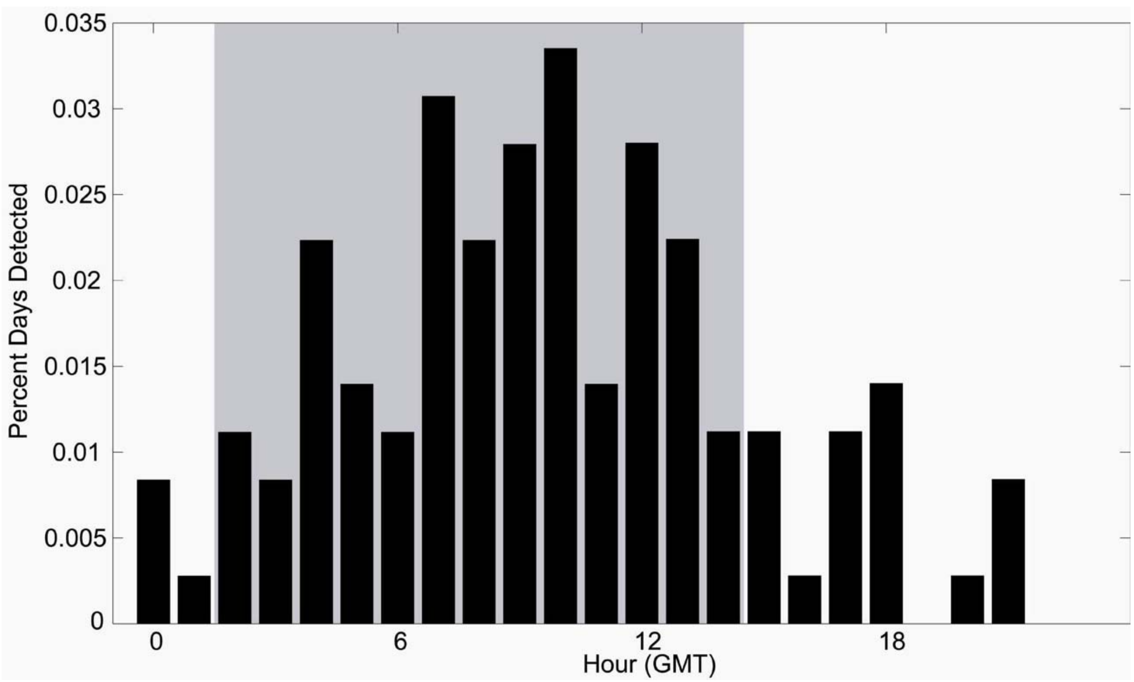


Figure 24: Occurrence of clicks, whistles, and burst-pulse sounds from unidentified odontocetes between June 2008 and June 2009 by hour of the day. Shaded grey area represents average night period at this location through the year.

Porpoises

Harbour (*Phocoena phocoena*) and Dall's porpoise (*Phocoenoides dalli*) were the most frequently sighted marine mammals during visual surveys (Table 2). Both Dall's and harbour porpoises produce clicks that contain energy from 115-149 kHz (Verboom & Kastelein 2003; authors' unpublished data), higher in frequency than the bandwidth of these recordings. High frequency narrow band (HFNB) clicks, with energy from 55-85 kHz and a narrower bandwidth than typical delphinid clicks, were frequently identified in this dataset (Figure 25). There is no known cetacean in the study area which produces echolocation clicks of this description, and these HFNB clicks are most likely a result of spectral aliasing of porpoise clicks (shifting of energy from above the recording band into the recording band). Given that Dall's porpoises are

more frequently sighted in the vicinity of the inshore site, these could be Dall's porpoise clicks. However, since no recordings are available during known presence of either species, this identification should be considered preliminary. As in previous years these clicks were detected, peak presence of HFNB clicks occurred in the fall (Oleson *et al.* 2009). However, presence of the clicks was relatively constant during the remainder of the year, with only notable decreases in August and January (Figure 26).

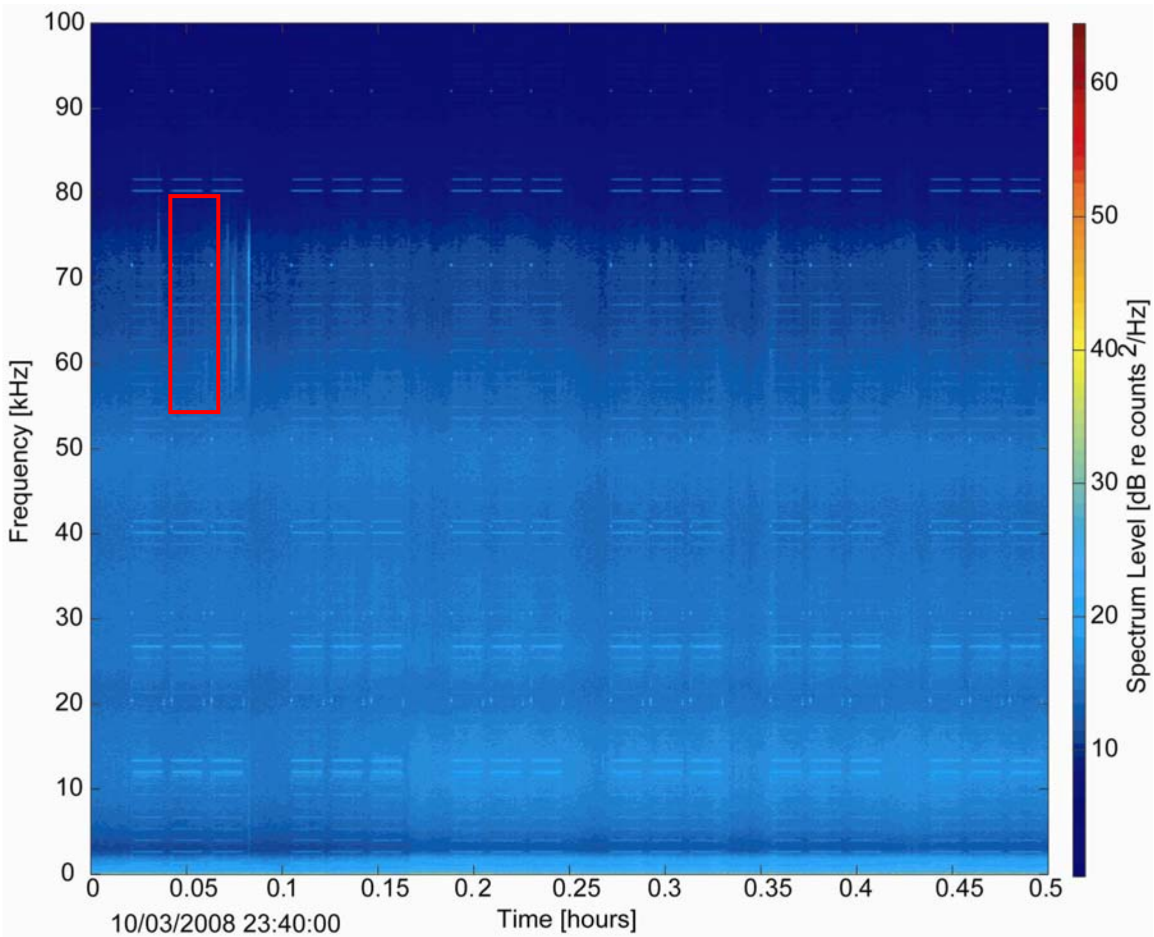


Figure 25: **LTSA of high frequency narrow bandwidth pulses (outlined by red box), likely aliased porpoise pulses, recorded at the inshore site in October 2008.**

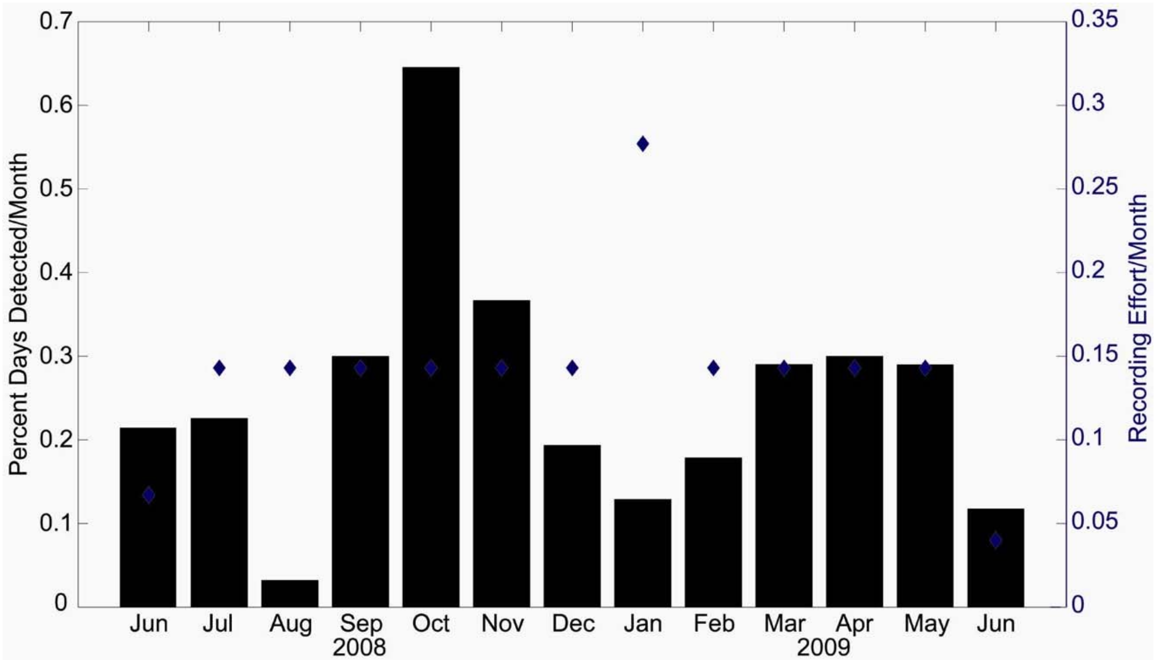


Figure 26: **Occurrence of high-frequency narrow-bandwidth (HFNB) clicks, thought to be produced by a porpoise, recorded between June 2008 and June 2009. Black bars represent the fraction of days clicks were detected in a month and blue diamonds represent monthly recording effort.**

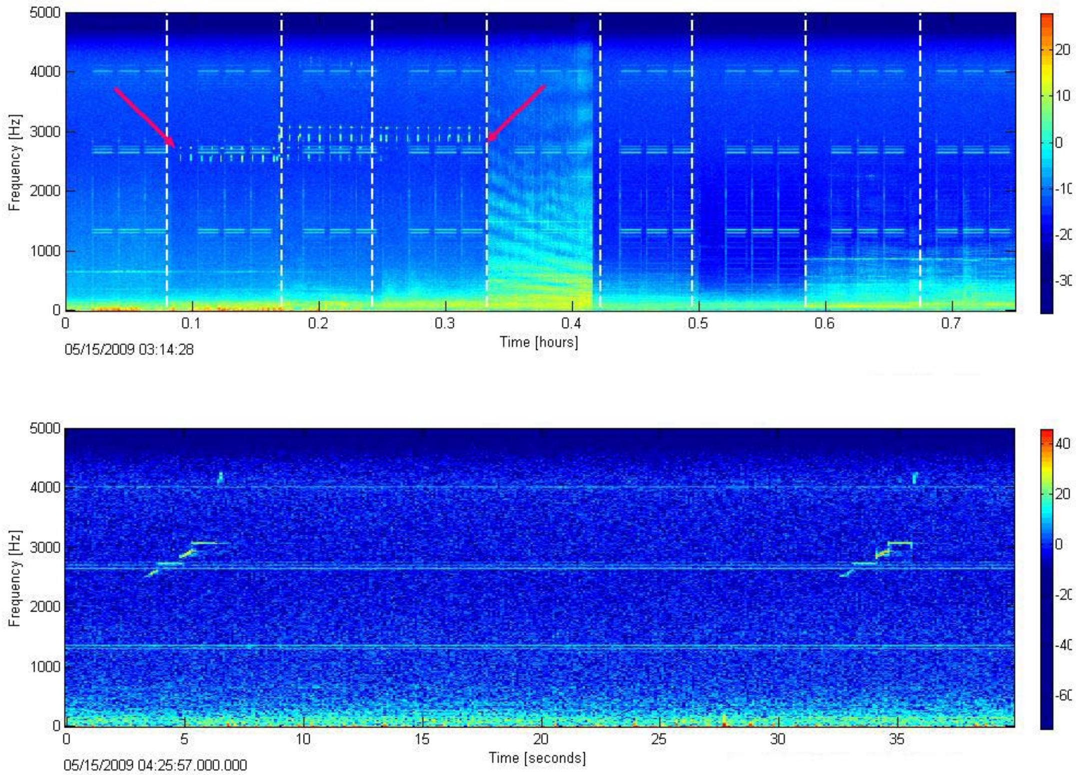
Pinnipeds

Pinniped sounds were detected only during two days: one in August and one in October 2008. They consisted mainly of barks sounding similar to those heard above water, with most energy between 400 and 600 Hz and of very short durations (< 1 s).

Anthropogenic Noise Sources

Mid-Frequency Active (MFA) Sonar

One occurrence of MFA sonar was recorded on 15 May 2009 (Figure 27). A total of 30 pings was recorded, lasting between 0.5 and 3 seconds with majority of the energy around 3 kHz.



<u>Figure 27:</u> LTSA (*above*) and spectrogram (*below*) of mid-frequency active (MFA) sonar recorded at the inshore site on 15 May 2009.

Explosions

Explosions were logged during the data analysis effort, and subsequently they were classified based on their maximum frequency and duration. The duration of each explosion was measured from the time series as the time between the onset of oscillations and the moment when the amplitude of the oscillations was ½ of the maximum amplitude (Figure 28). Based on these measurements, we conclude that logged explosions reported here are probably not from Naval exercises, but are small explosions such as those produced from "seal bombs" used by fishermen. These explosions were more common in the summer and in January (Figure 29), and occur almost entirely during daytime hours (Figure 30).

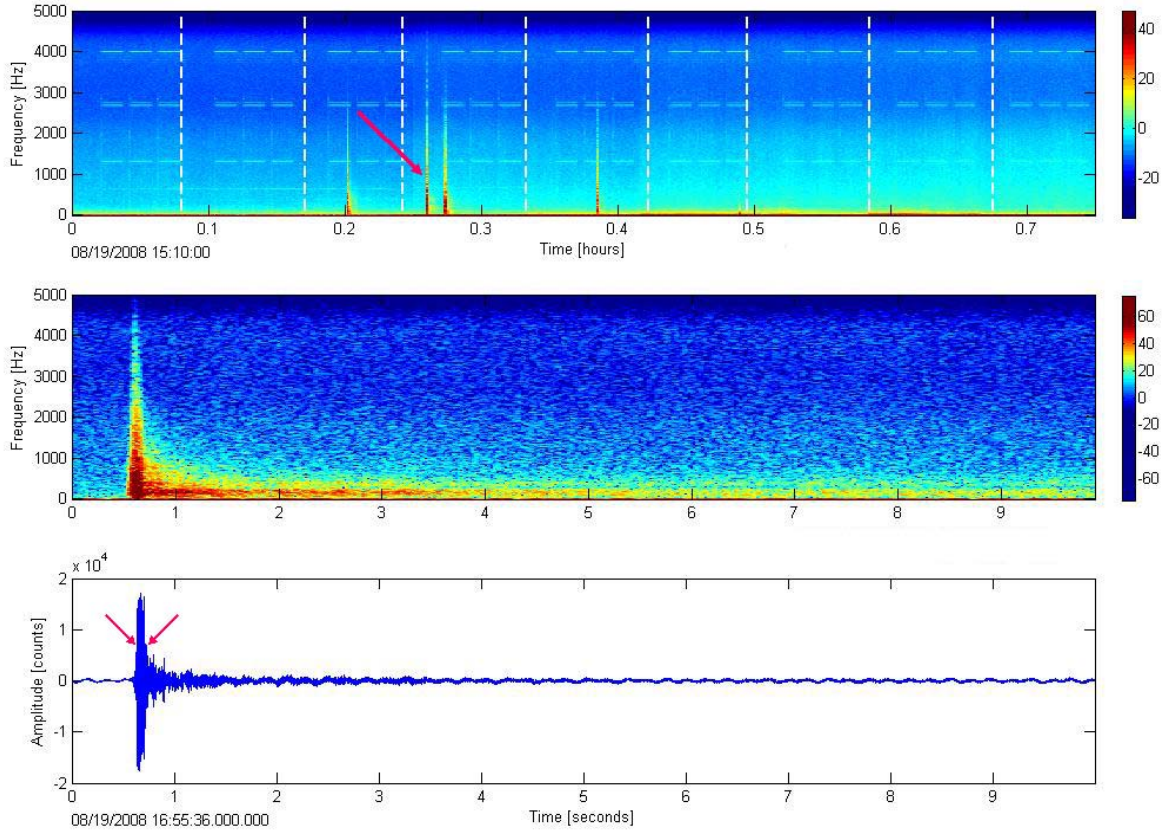


Figure 28: LTSA of several explosions recorded in August 2008, with spectrogram and time series of one event. Arrows in the time series plot denote times when start and end of the signal were measured, as described in the text.

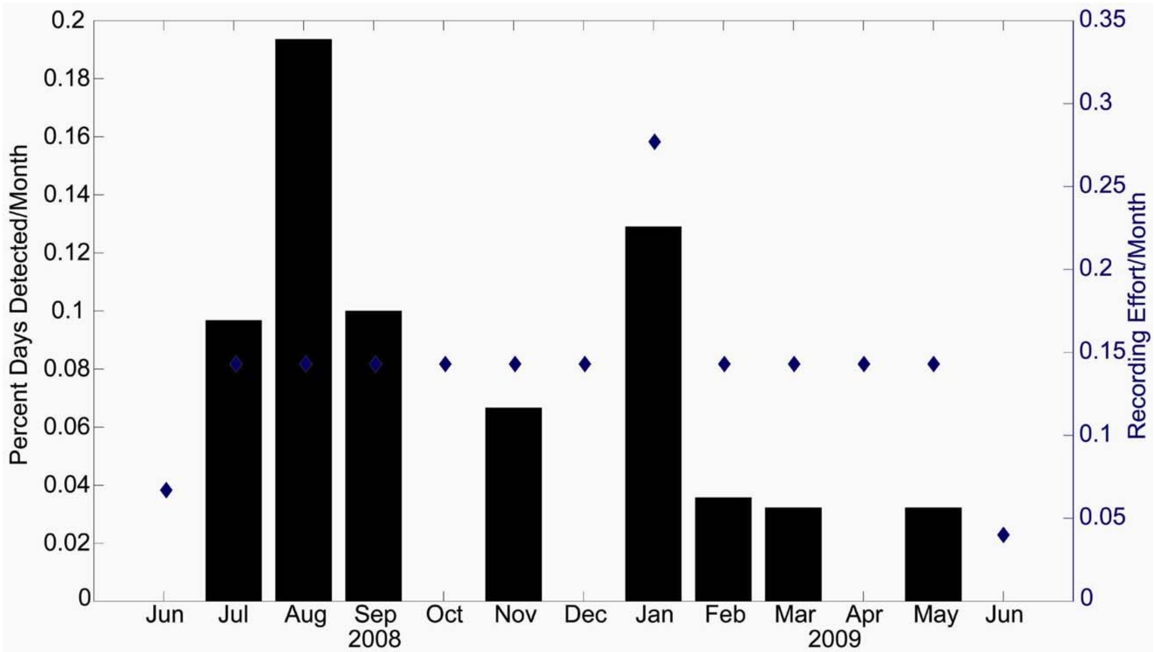


Figure 29: Occurrence of explosions between June 2008 and June 2009. Black bars represent the fraction of days explosions were detected in a month and blue diamonds represent monthly recording effort.

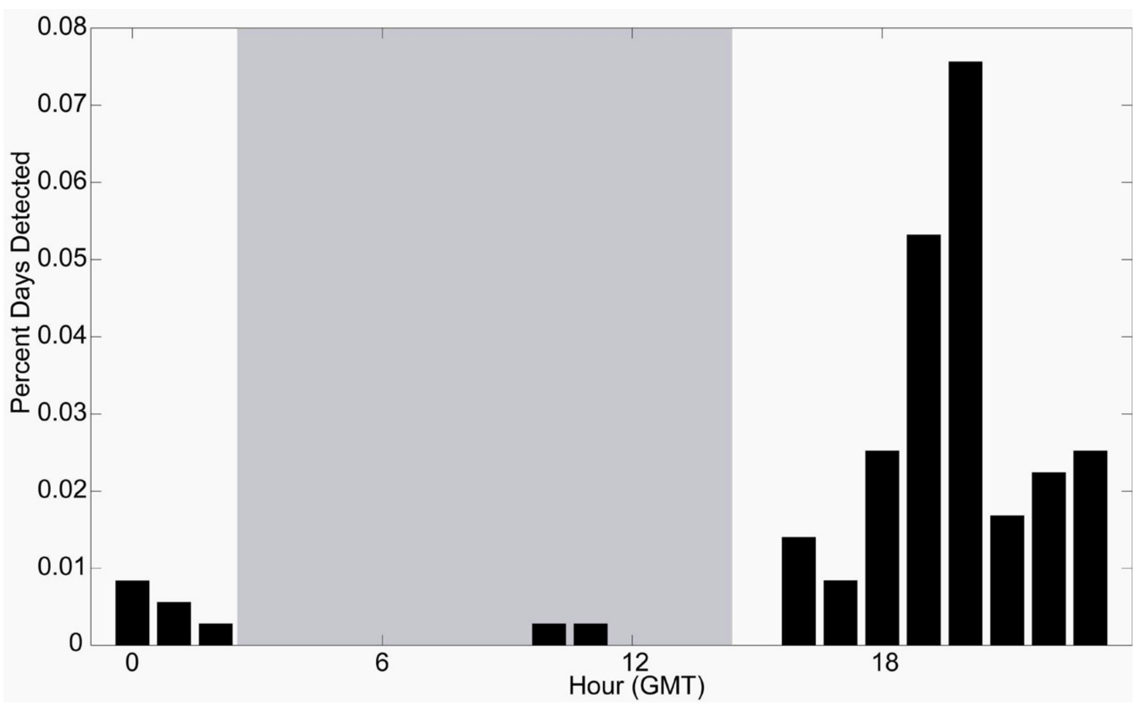


Figure 30: Occurrence of explosions between June 2008 and June 2009 by hour of the day. Shaded grey area represents average night period at this location through the year.

Shipping

When a ship passes relatively close to the HARP, broadband noise can be easily observed and classified as shipping noise. Most broadband ship and boat noise fell within a single duty cycle throughout in this data, indicating ships and boats are generally passing through this area. Shipping noise was common year-round, but it decreased in the fall, with a dramatic decline in December 2008 (Figure 31).

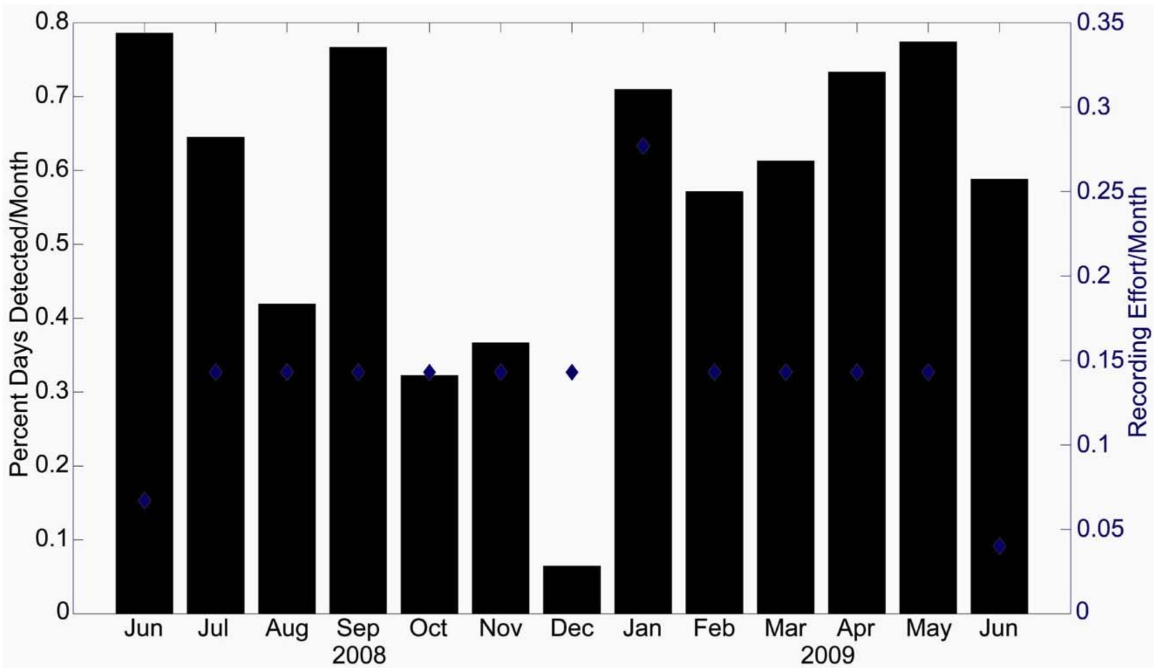


Figure 31: Occurrence of boat and ship noise between June 2008 and June 2009. Black bars represent the fraction of days boats and ships were detected in a month and blue diamonds represent monthly recording effort.

Acoustic and Visual Monitoring for Marine Mammals near Hawaii

Erin M. Oleson[1,2], Robin Baird[3], Erin Falcone[3], Greg Schorr[3], Annie Douglas[3], Daniel Webster[4], and Dan McSweeney[5]

[1]UCSD Scripps Institution of Oceanography
[2] NOAA-NMFS-Pacific Islands Fisheries Science Center
[3]Cascadia Research Collective
[4]Bridger Consulting
[5]Wild Whale Research Foundation

Project Background

Off the west coast of the island of Hawaii, the steep bathymetric slope results in high odontocete species diversity in a relatively small area, with both shallow-water (*e.g.*, spinner or bottlenose dolphins) and deep-water (*e.g.*, beaked whales, dwarf sperm whales) species found in relatively close proximity. Surveys to assess odontocete species occurrence have been undertaken in that area yearly since 2002 (*e.g.*, McSweeney *et al.* 2007, Baird *et al.* 2008a, Baird *et al.* 2008b). Thus there is considerable information on the seasonal presence and relative abundance of different species. Although some of the species in this region have been acoustically recorded previously, most of these recordings lack adequate bandwidth to classify the vocalizations to species. For other species, such as beaked whales and dwarf and pygmy sperm whales, very few researchers have attempted to record these species around Hawaii. The relatively rare and elusive odontocetes are likely to be some of the most vulnerable to U.S. Navy sonar exercises. Year-round acoustic monitoring for these species and identification of their species-specific sounds through joint visual and acoustic surveys is particularly important.

Objectives

1. Year-round high-frequency acoustic recordings off the west side of the island of Hawaii in an area of known high species diversity.
2. Obtaining acoustic recordings of odontocetes during visual surveys, with particular reference to species for which no or few recordings are available.
3. Regular visual surveying in the vicinity of the acoustic monitoring site to obtain additional information on the relative occurrence of odontocete cetaceans in the area for comparisons with acoustic data obtained.

Data Collected

A 2-month pilot effort was undertaken from August to October 2007. A single HARP was deployed off the west coast of the island of Hawaii and recorded continuously at 200 kHz sample rate. A long-term study began in earnest in April 2008 with redeployment of the HARP

at the same location off the Kona coast. The HARP has since been recovered and redeployed four times in conjunction with visual surveys in the area. With the exception of the period mid-October 2008 to mid-February 2009, we have collected acoustic occurrence data year-round at this location. The HARP was most recently redeployed in April 2009 and will record until October of 2009.

All deployments at the Kona site have recorded data with an acoustic sample rate of 200 kHz, though the duty cycle has varied depending on the timing of the next scheduled visual survey in the area (Table 5). The HARP is deployed along the steep slope off the west shore of Hawaii in approximately 700 m of water (Figure 32). The steep bathymetric slope provides a unique opportunity to record both pelagic and coastal species at the same location. The HARP location was also strategically chosen to be accessible from Honokohau harbor, allowing for daily visual surveys of the HARP location during periods of the visual survey effort.

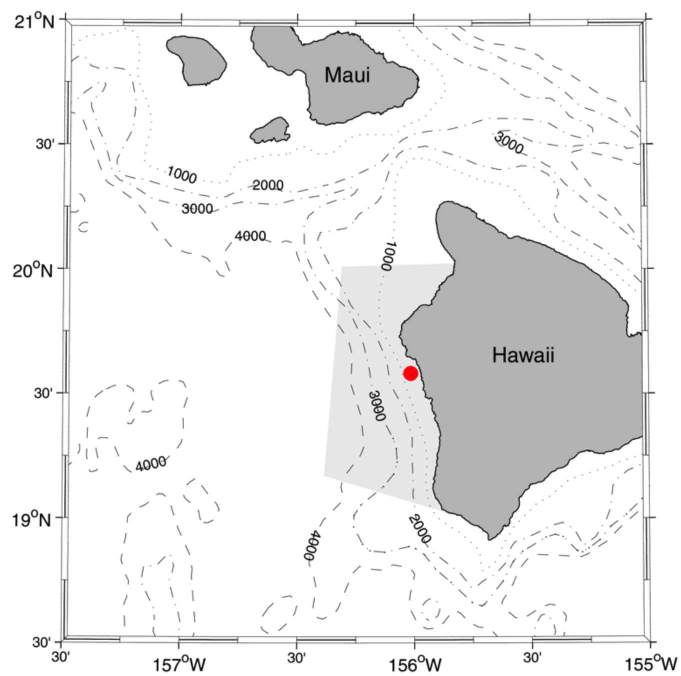


Figure 32: **Study area on the west side of the island of Hawaii. The acoustic monitoring location is shown as a red circle and the approximate boundary of the visual survey area by light gray shading.**

Table 5: Acoustic data collection near the island of Hawaii since August 2007 – October 2009.

Data Name	HARP Deployment and Recovery Dates	Actual Recording Period (Days)	HARP Sample Rate and Duty-Cycle (X of Y minutes)
Hawaii 01	deploy: August 10, 2007 recover: October 19, 2007	August 10 - October 4, 2007 (55 days)	200 kHz continuous
Hawaii 02	deploy: April 18, 2008 recover: July 4, 2008	April 18 - July 4, 2008 (77 days)	200 kHz 5 / 8
Hawaii 03	deploy: July 7, 2008 recover: December 10, 2008	July 8 - October 15, 2008 (99 days)	200 kHz 5 / 15
Hawaii 04	deploy: December 15, 2008 recover: February 7, 2009	No Data	200 kHz continuous
Hawaii 05	deploy: February 9, 2009 recover: April 19, 2009	February 10 - March 31, 2009 (49 days)	200 kHz continuous
Hawaii 06	deploy: April 22, 2009 recover: October 22, 2009	April 23 – August 18, 2009 (117 days)	200 kHz 5 / 15

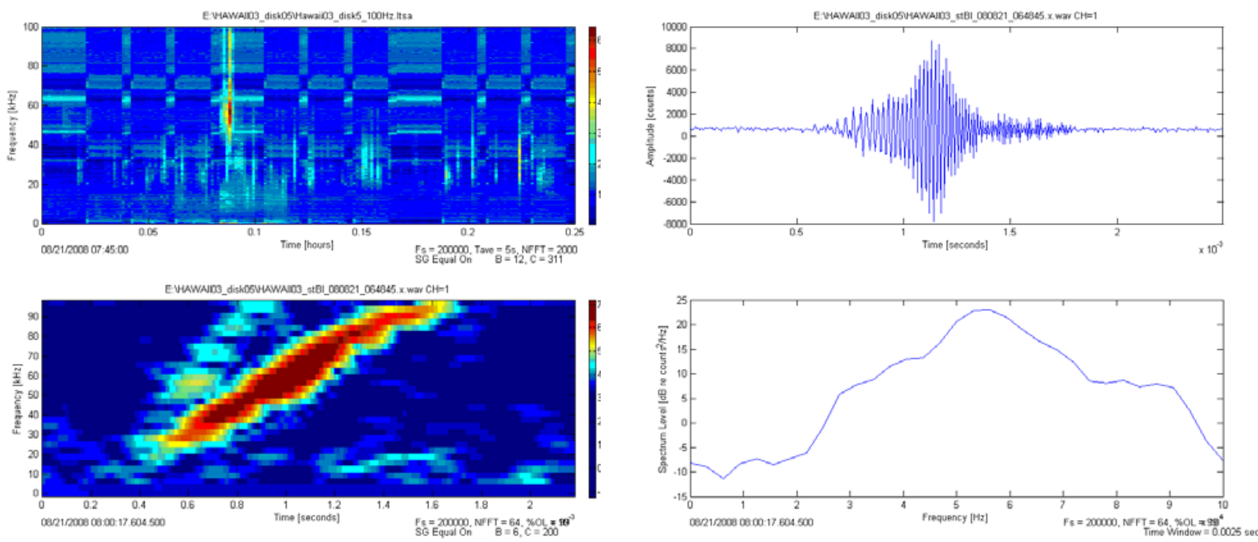
In addition to long-term acoustic recordings, recordings have been made in the presence of known species in order to build a library of reference recordings to aid in identification of acoustic detections within the autonomous dataset. Reference recordings have been obtained using a hydrophone deployed from the small boat during encounters with single species groups. We have obtained 23 recordings in the presence of 7 species-- Blainville's beaked whale, pygmy killer whale, melon-headed whale, short-finned pilot whale, rough-toothed dolphin, Risso's dolphin, and pygmy sperm whale. Association of known species to recorded calls has also been obtained by conducting visual surveys around the HARP and by comparing the time and location of satellite tagged animals to odonotocete vocalizations detected on the HARP. There have been 23 sightings of 5 cetacean species within 1 km of the HARP-- short-finned pilot whales, Blainville's beaked whale, rough-toothed dolphin, false killer whales, and pygmy sperm whale. Seven of those cetacean groups were linked with odontocete calls recorded on the HARP. In addition, there have been several occasions where individuals or groups of satellite tagged animals passed over or very near the HARP, including several occurrences of short-finned pilot whales, Blainville's beaked whales, false killer whales, and a single pass by a group of tagged melon-headed whales. In most of these occurrences, echolocation clicks and whistles thought to be produced by the passing groups have been recorded on the HARP.

Results

Recordings of known species obtained from either 1) boat-based surveys, 2) associating sounds heard on the HARP with animals seen within 1 km of the HARP location, or 3) associating sounds heard on the HARP with animals known to have swum over or very close to the HARP based on satellite location data, have resulted in the association of several stereotyped sounds with specific species. Through combination of the visual, acoustic, and satellite tagging datasets we have confirmed that Blainville's beaked whales off Kona produce sounds consistent with those heard in other regions (Johnson *et al*. 2006), and that these sounds can be readily

identified based on the long-duration (200-300 µs) upsweep and the lower 10 dB bandwidth of those sweeps (~28 kHz). Sounds produced by false killer whales and pilot whales are also identifiable in the HARP data based on data collected in the presence of those species. A high level of variation in the sounds of pygmy killer whales, melon-headed whales, and rough-toothed dolphins has so far prevented conclusive association of specific clicks or whistle characteristics with those species. However, a more quantitative analysis may result in significant species-specific features.

In addition to Blainville's beaked whale sounds, Cuvier's beaked whale sounds have been recorded by the Kona HARP, as well as a number of other upswept clicks that have not yet been identified to species. In particular, a very long duration (>600 µs) upswept click previously reported from Cross Seamount, approximately 100 nmi west of the Island of Hawaii, has been heard infrequently (Figure 33). Several other odontocete vocalizations are present within the record, yet remain to be identified to species pending further species-specific acoustic data collection.



<u>Figure 33:</u> Upswept "beaked whale" clicks previously reported from Cross Seamount, shown here in the Kona HARP data.

Although most sounds in the HARP dataset cannot yet be identified to species, some are easily recognized, such that the seasonal and daily occurrence of those sounds can be evaluated (Figure 34). For example, very high frequency "70 kHz" clicks have been recorded frequently by the HARP and are easily recognizable due to their occurrence in short (<10 min) bouts and the spectral nature of the sounds (Figure 35). These sounds have been recorded in all months monitored to date (April through October) and do not have a significant diel-cycling in their daily occurrence (Figure 36). These sounds often occur in recurring bouts of 15 to 90 minutes, possibly indicating successive foraging dives near the HARP.

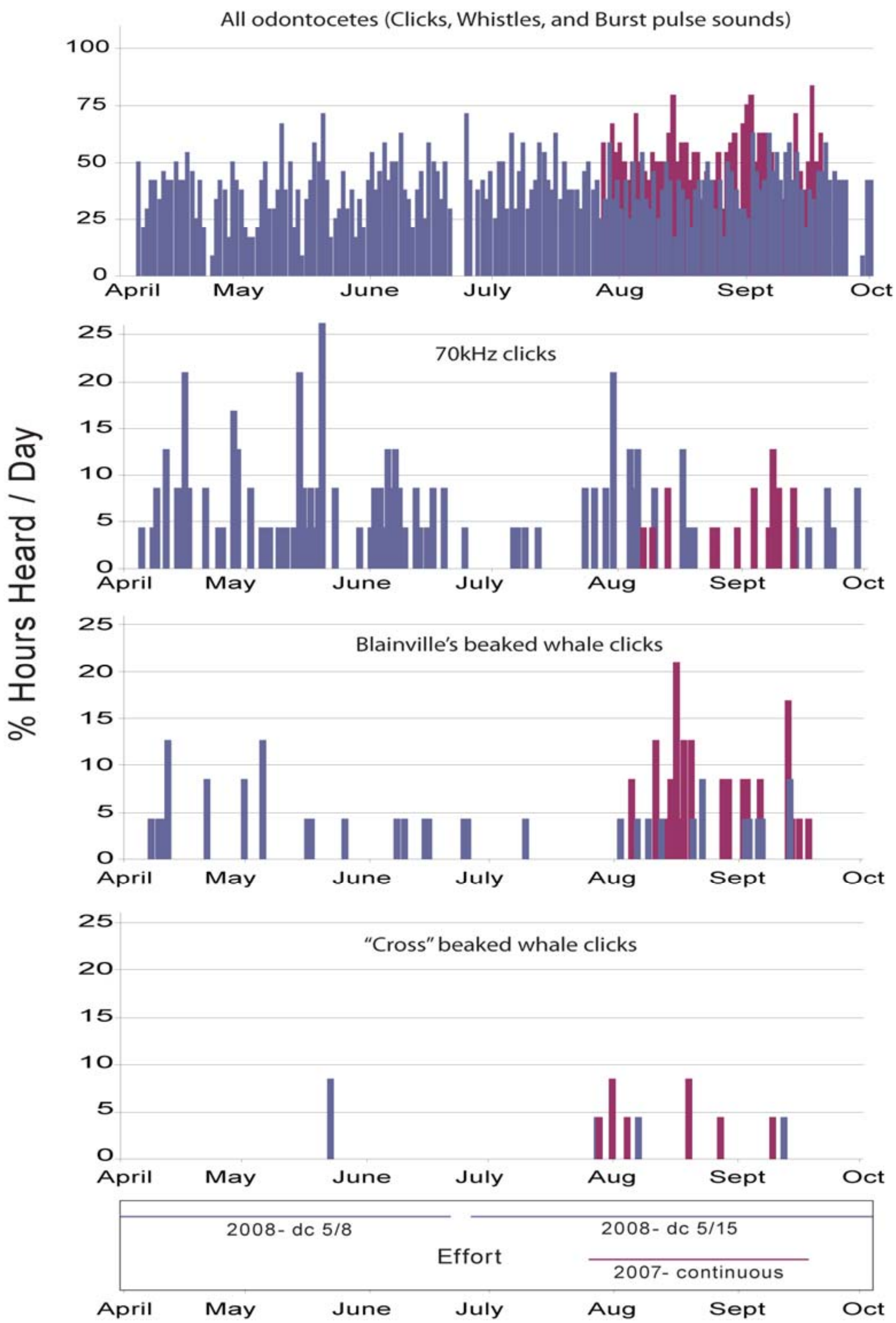
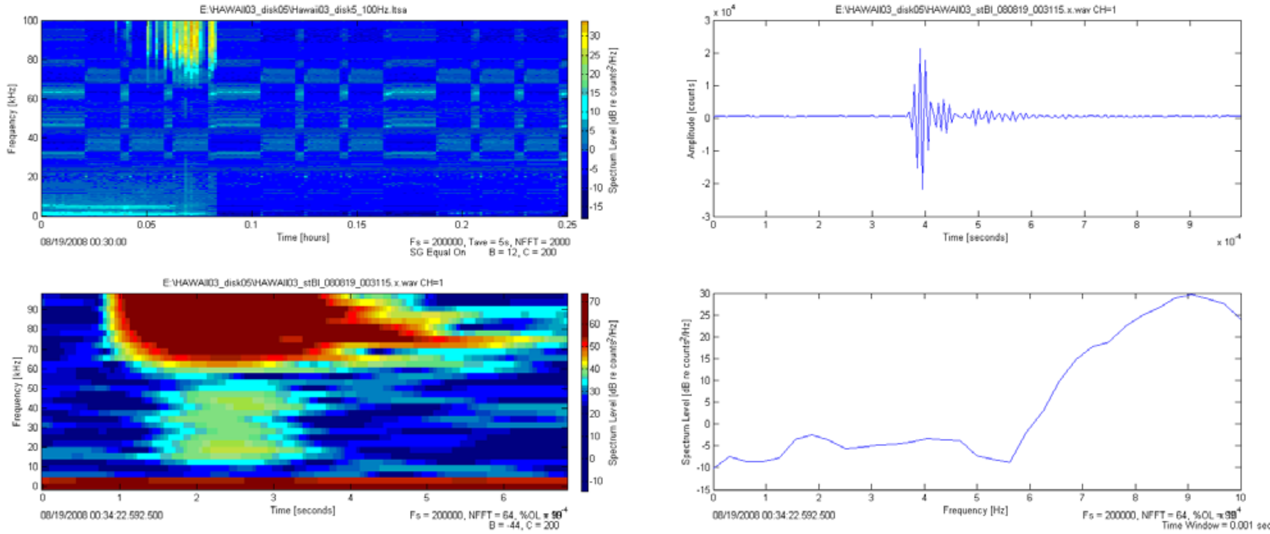
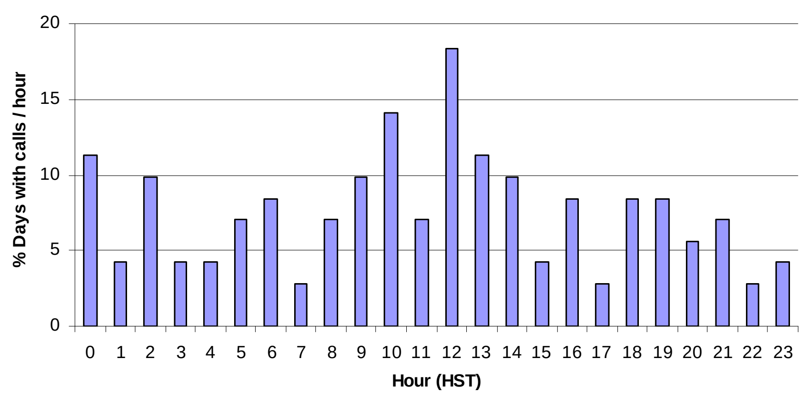


Figure 34: **Seasonal occurrence, as observed on the Kona HARP, of all odontocete sounds (*top panel*), and specific sounds or species (*middle panels*). Recording effort and the associated duty cycle (dc) during each deployment is noted in the *bottom panel*.**



<u>Figure 35:</u> Very high frequency (*aka* 70 kHz clicks) recorded on the Kona HARP. It is clear from the spectral data that the clicks extend beyond the 100 kHz frequency cut-off of the HARP. The species responsible for producing these sounds is not yet known.



<u>Figure 36:</u> Hourly occurrence of very high-frequency "70 kHz" clicks on days when this call type was heard. Although there appears to be a slight increase at noon, the hourly distribution of this call type is not significant.

It should be noted that the duty cycle for acoustic recording has been different with each HARP deployment to date. The differences in the amount of recording time per day (varying from continuous to 5 minutes out of each 15 minutes) may have resulted in differences in the apparent occurrence of cetaceans during August to October 2007 versus the same period in 2008. For all but 70 kHz clicks, each sound type appears more common in the August to October 2007 period versus the 2008 period (Figure 34), possibly attributable to missed calls during the "off" period of the duty cycle. The impact of duty cycling can be simulated, and we will investigate

whether the difference in detection rate between 2007 and 2008 is likely to be attributed to the duty cycle difference.

Echosounders & Other Sonars

Fishing echosounders with frequencies near 28, 50, and 80 kHz are the most commonly detected sound within this dataset. Echosounders can be detected at all hours of the day, though are significantly more common during daylight, as expected, given the largely daytime fishing habits of recreational fishers. Fishing echosounders were heard during every day of recording effort at 7:00 to 8:00 am and at 2:00 pm within a subset of the dataset from August to October 2007.

ASW sonar was also detected on a few occasions, including during three periods on July 27 and one on July 28, 2008, a few days prior to the start of multi-national Naval exercises RIMPAC. ASW sonar was also detected during three periods on June 28, 2008.

Literature Cited

BAIRD, R. W., A. M. GORGONE, D. J. MCSWEENEY, D. L. WEBSTER, D. R. SALDEN, M. H. DEAKOS, A. D. LIGON, G. S. SCHORR, J. BARLOW, and S. D. MAHAFFY. **2008a**. False killer whales (*Pseudorca crassidens*) around the main Hawaiian Islands: long-term site fidelity, inter-island movements, and association patterns. *Marine Mammal Science* **24:** 591-612.

BAIRD, R. W., D. L. WEBSTER, S. D. MAHAFFY, D. J. MCSWEENEY, J. R. SCHOENHERR, and A. D. LIGON. **2008b**. Site fidelity and association patterns in a deep-water dolphin: rough-toothed dolphins (*Steno bredanensis*) in the Hawaiian archipelago. *Marine Mammal Science* **24:** 535-553.

BURTENSHAW, J. C., E. M. OLESON, J. A. HILDEBRAND, M. A. MCDONALD, R. K. ANDREW, B. M. HOWE, and J. A. MERCER. **2004**. Acoustic and satellite remote sensing of blue whale seasonality and habitat in the Northeast Pacific. *Deep Sea Research Part II: Topical Studies in Oceanography* **51:** 967-986.

CALAMBOKIDIS, J. and J. BARLOW. **2004**. Abundance of blue and humpback whales in the eastern North Pacific estimated by capture-recapture and line-transect methods. *Marine Mammal Science* **20:** 63-85.

CALAMBOKIDIS, J., T. CHANDLER, E. FALCONE, and A. DOUGLAS. **2004a**. Research on large whales off California, Oregon, and Washington in 2003. *Contract Report to Southwest Fisheries Science Center*, available at http://cascadiaresearch.org/reports/rep-03-SW-final.pdf, Olympia, WA. 48 pp.

CALAMBOKIDIS, J., G. H. STEIGER, D. K. ELLIFRIT, B. L. TROUTMAN, and C. E. BOWLBY. **2004b**. Distribution and abundance of humpback whales and other marine mammals off the northern Washington coast. *Fisheries Bulletin* **102:** 563-580.

CRANE, N. L. and K. LASHKARI. **1996**. Sound production of gray whales, *Eschrichtius robustus*, along their migration route: A new approach to signal analysis. *The Journal of the Acoustical Society of America* **100:** 1878-1886.

DUNLOP, R. A., M. J. NOAD, D. H. CATO, and D. STOKES. **2007**. The social vocalization repertoire of east Australian migrating humpback whales (*Megaptera novaeangliae*). *Journal of the Acoustical Society of America* **122:** 2893-2905.

GREEN, G. A., M. A. SMULTEA, C. E. BOWLBY, and R. A. ROWLETT. **1992**. Delphinid aerial surveys in Oregon and Washington offshore waters. *National Marine Fisheries Service*, Seattle, Washington. 100 pp.

JOHNSON, M., P. T. MADSEN, W. M. X. ZIMMER, N. A. DE SOTO, AND P. L. TYACK. **2006**. Foraging Blainville's beaked whales (*Mesoplodon densirostris*) produce distinct click types matched to different phases of echolocation. *Journal of Experimental Biology* **209:** 5038-5050.

MCDONALD, M. A., S. L. MESSNICK, and J. A. HILDEBRAND. **2006**. Biogeographic characterisation of blue whale song worldwide: using song to identify populations. *Journal of Cetacean Research and Management* **8:** 55-65.

MCSWEENEY, D. J., R. W. BAIRD, and S. D. MAHAFFY. **2007**. Site fidelity, associations and movements of Cuvier's (*Ziphius cavirostris*) and Blainville's (*Mesoplodon densirostris*) beaked whales off the Island of Hawai'i. *Marine Mammal Science* **23:** 666-687.

MOHL, B., M. WAHLBERG, P. T. MADSEN, A. HEERFORDT, and A. LUND. **2003**. The monopulsed nature of sperm whale clicks. *Journal of the Acoustical Society of America* **114:** 1143-1154.

OLESON, E. M., J. CALAMBOKIDIS, W. C. BURGESS, M. A. MCDONALD, C. A. LEDUC, and J. A. HILDEBRAND. **2007a**. Behavioral context of call production by eastern North Pacific blue whales. *Marine Ecology-Progress Series* **330:** 269-284.

OLESON, E. M., J. CALAMBOKIDIS, E. A. FALCONE, G. S. SCHORR, and J. A. HILDEBRAND. **2009**. Acoustic and visual monitoring of cetaceans along the outer Washington Coast. *Naval Postgraduate School report* NPS-OC-09-001.

OLESON, E. M., S. M. WIGGINS, and J. A. HILDEBRAND. **2007b**. Temporal separation of blue whale call types on a southern California feeding ground. *Animal Behaviour* **74:** 881-894.

PAYNE, R. S. and S. MCVAY. **1971**. Songs of humpback whales. *Science* **173:** 585-597.

SHELDEN, K. E. W., D. J. RUGH, J. L. LAAKE, J. M. WAITE, P. J. GEARIN, and T. R. WAHL. **2000**. Winter Observations of Cetaceans off the Northern Washington Coast. *Northwestern Naturalist* **81:** 54-59.

SOLDEVILLA, M. S., E. E. HENDERSON, G. S. CAMPBELL, S. M. WIGGINS, J. A. HILDEBRAND, and M. A. ROCH. **2008**. Classification of Risso's and Pacific white-sided dolphins using spectral properties of echolocation clicks. *The Journal of the Acoustical Society of America* **124:** 609-624.

STIMPERT, A. K., W. W. L. AU, S. E. PARKS, T. HURST, and D. N. WILEY. **2011**. Common humpback whale (*Megaptera novaeangliae*) sound types for passive acoustic monitoring. *Journal of the Acoustical Society of America* **129:** 476-482.

VERBOOM, W. C. and R. A. KASTELEIN. **2003**. Structure of harbour porpoise (*Phocoena phocoena*) acoustic signals with high repetition rates. *Echolocation in bats and dolphins***:** 40–43. University of Chicago Press, Chicago, IL.

WATKINS, W. A., M. A. DAHER, G. M. REPPUCCI, J. E. GEORGE, D. L. MARTIN, N. A. DIMARZIO, and D. P. GANNON. **2000**. Seasonality and distribution of whale calls in the North Pacific. *Oceanography* **13:** 62-67.

Appendix

Table A-I: **Sightings of cetaceans during each survey conducted from August 2004 through September 2008 off the Washington coast.** ***(S = number of sightings, An = number of animals).***

Date	Humpback Whale # S	Humpback Whale # An	Gray Whale # S	Gray Whale # An	Minke Whale # S	Minke Whale # An	Fin whale # S	Fin whale # An	Killer Whale # S	Killer Whale # An	UnID Whale # S	UnID Whale # An	UnID beaked whale # S	UnID beaked whale # An	Cuvier's beaked whale # S	Cuvier's beaked whale # An	N. Right Whale Dolphin # S	N. Right Whale Dolphin # An	Pac. White-sided Dolphin # S	Pac. White-sided Dolphin # An	Risso's dolphins # S	Risso's dolphins # An	Harbor Porpoise # S	Harbor Porpoise # An	Dalls Porpoise # S	Dalls Porpoise # An
8/16/04	2	5																					5	12		
10/11/04	1	3	1	1																			1	2	2	12
11/9/04					1	1																	2	2	1	1
12/23/04			2	4																			3	7	1	9
12/28/04			1	1																			1	1	1	10
2/17/05			1	1									1	2									4	7		
2/25/05	2	3	1	2																			10	18	3	14
3/24/05			7	9																			3	4		
4/26/05			2	2							1	1											3	4	1	5
5/26/05	3	5	1	1																						
6/3/05	1	3							1	7							1	4	4	246					1	5
6/29/05																			7	242			5	14		
7/29/05	9	16															1	5	1	400			1	3		
8/31/05	6	12																					5	12	1	3
9/28/05	6	10																					5	12		
10/20/05	8	19							1	1													1	4	2	20
11/18/05	1	3																								
12/8/05							1	2	1	13			1	1									1	3		
3/12/06																							2	4	4	10
3/20/06			4	8																			1	3		
4/5/06			3	5					1	11													3	8		
5/21/06			6	6							1	1											2	2	1	5
6/12/06															1	3							2	6	1	8
7/30/06	6	7																			2	38	5	8	2	8
9/8/06	3	5																	2	306			5	20	3	9
10/10/06	5	8																							2	11
1/12/07			4	10																			4	5		
1/31/07			1	3																						

Date	Humpback Whale		Gray Whale		Minke Whale		Fin whale		Killer Whale		UnID Whale		UnID beaked whale		Cuvier's beaked whale		N. Right Whale Dolphin		Pac. White-sided Dolphin		Risso's dolphins		Harbor Porpoise		Dalls Porpoise	
	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An
4/3/07			6	9					1	13													1	2		
5/16/07																										
6/8/07	7	11	1	12																					3	8
6/26/07	4	6	2	3															2	52			2	3	2	9
8/30/07	3	8															1	50	1	400			1	1	5	25
9/1/07	2	4	3	27																			1	3		
10/31/07	5	8																					9	24	2	6
1/23/08			2	3					1	6													1	2		
3/5/08			1	1																			2	2		
4/1/08			5	6																			1	2		
5/29/08	2	4	1	2																			12	21	2	14
7/2/08	1	1																	1	35			4	14	2	5
8/10/08	2	5																					3	4	1	8
9/2/08	1	1																					3	5	1	1
Total	80	147	55	116	1	1	1	2	6	51	2	2	2	3	1	3	3	59	18	1681	2	38	114	244	44	206

<u>Table A-II:</u> Sightings of pinnipeds during each survey conducted from August 2004 through September 2008 off the Washington coast. ***(S = number of sightings, An = number of animals)*.**

Date	California Sea Lion # S	California Sea Lion # An	Stellar Sea Lion # S	Stellar Sea Lion # An	Northern Fur Seal # S	Northern Fur Seal # An	Harbor Seal # S	Harbor Seal # An	Northern Elephant Seal # S	Northern Elephant Seal # An	UnID Pinniped # S	UnID Pinniped # An
8/16/04					4	4						
10/11/04	2	2										
11/9/04							1	1				
12/23/04					3	3	1	1				
12/28/04					1	6						
2/17/05	3	4			1	1						
2/25/05	1	1	1	1	2	2	3	3				
3/24/05	3	4	1	1			1	1				
4/26/05					1	1	6	699				
5/26/05	1	10			5	80						
6/3/05					7	9			1	1		
6/29/05	1	1			5	7	1	1			2	2
7/29/05												
8/31/05												
9/28/05	1	1	1	1	1	1	1	1			1	3
10/20/05			2	8	2	2	1	1				
11/18/05	2	3										
12/8/05	1	1										
3/12/06	1	2			1	1						
3/20/06			1	1			5	7				
4/5/06												
5/21/06	1	1			1	1			3	3		
6/12/06					3	3						
7/30/06							1	1				
9/8/06												
10/10/06	1	2										
1/12/07					2	4			1	1		
1/31/07					1	1			1	1		
4/3/07					1	1	1	1				
5/16/07					1	1	1	1	1	1		
6/8/07	1	1			9	14			1	1		
6/26/07	1	1	1	1	2	8						
8/30/07					4	4						
9/1/07					1	1						
10/31/07	4	152	1	30			1	1				
1/23/08	1	1					1	1				
3/5/08												
4/1/08									1	1		
5/29/08			3	13	2	2	1	1				
7/2/08												
8/10/08												
9/2/08							1	2	1	1		
Total	25	187	11	56	60	157	27	723	10	10	3	5

Initial Distribution List

1.	Defense Technical Information Center 8725 John J. Kingman Rd., STE 0944 Ft. Belvoir, VA 22060-6218	2
2.	Dudley Knox Library, Code 013 Naval Postgraduate School Monterey, CA 93943-5100	2
3.	Erin Oleson National Marine Fisheries Service Pacific Islands Fisheries Science Center Honolulu, HI	1
4.	John Hildebrand Scripps Institution of Oceanography University of California La Jolla, CA	1
5.	John Calambokidis Cascadia Research Collective Olympia, WA	1
6.	Greg Schorr Cascadia Research Collective Olympia, WA	1
7.	Erin Falcone Cascadia Research Collective Olympia, WA	1
8.	Ching-Sang Chiu Naval Postgraduate School Monterey, CA	1
9.	Curtis A. Collins Naval Postgraduate School Monterey, CA	1
10.	Thomas A. Rago Naval Postgraduate School Monterey, CA	1

11. Tetyana Margolina 1
Naval Postgraduate School
Monterey, CA

12. Chris Miller 1
Naval Postgraduate School
Monterey, CA

13. John Joseph 1
Naval Postgraduate School
Monterey, CA

14. Katherine Whitaker 1
Pacific Grove, CA

15. Frank Stone 1
CNO(N45)
Washington, D.C.

16. Jay Barlow 1
Southwest Fisheries Science Center, NOAA
La Jolla, CA

17. CAPT Ernie Young, USN (Ret.) 1
CNO(N45)
Washington, D.C.

18. Dale Liechty 1
CNO(N45)
Washington, D.C.

19. Dave Mellinger 1
Oregon State University
Newport, OR

20. Kate Stafford 1
Applied Physics Laboratory
University of Washington
Seattle, CA

21. Sue Moore 1
NOAA at Applied Physics Laboratory
University of Washington
Seattle, WA

22.	Petr Krysl University of California La Jolla, CA	1
23.	Mark McDonald Whale Acoustics Bellvue, CO	1
24.	Ted Cranford San Diego State University San Diego, CA	1
25.	Monique Fargues Naval Postgraduate School Monterey, CA	1
26.	Mary Ann Daher Woods Hole Oceanographic Institution Woods Hole, MA	1
27.	Heidi Nevitt NAS North Island San Diego, CA	1
28.	Rebecca Stone Naval Postgraduate School Monterey, CA	1
29.	Sean M. Wiggins Scripps Institution of Oceanography University of California La Jolla, CA	1
30.	E. Elizabeth Henderson Scripps Institution of Oceanography University of California La Jolla, CA	1
31.	Gregory S. Campbell Scripps Institution of Oceanography University of California La Jolla, CA	1
32.	Marie A. Roch San Diego State University San Diego, CA	1

33.	Anne Douglas Cascadia Research Collective Olympia, WA	1
34.	Julie Rivers COMPACFLT Pearl Harbor, HI	1
35.	Jenny Marshall Naval Facilities Engineering Command San Diego, CA	1
36.	Chip Johnson COMPACFLT Pearl Harbor, HI	1
37.	CDR Len Remias U.S. Pacific Fleet Pearl Harbor, HI	1
38.	LCDR Robert S. Thompson U.S. Pacific Fleet Pearl Harbor, HI	1
39.	Jene J. Nissen U. S. Fleet Forces Command Norfolk, VA	1
40.	W. David Noble U. S. Fleet Forces Command Norfolk, VA	1
41.	David T. MacDuffee U. S. Fleet Forces Command Norfolk, VA	1
42.	Keith A. Jenkins Naval Facilities Engineering Command, Atlantic Norfolk, VA	1
43.	Joel T. Bell Naval Facilities Engineering Command, Atlantic Norfolk, VA	1

44.	Mandy L. Shoemaker Naval Facilities Engineering Command, Atlantic Norfolk, VA	1
45.	Anurag Kumar Naval Facilities Engineering Command, Atlantic Norfolk, VA	1
46.	Merel Dalebout University of New South Wales Sydney, Australia	1
47.	Robin W. Baird Cascadia Research Collective Olympia, WA	1
48.	Brenda K. Rone National Marine Mammal Laboratory Seattle, WA	1
49.	Phil Clapham National Marine Mammal Laboratory Seattle, WA	1
50.	Laura J. Morse National Marine Mammal Laboratory Seattle, WA	1
51.	Anthony Martinez NOAA Southeast Fisheries Science Center Miami, FL	1
52.	Darlene R. Ketten Woods Hole Oceanographic Institution Woods Hole, MA	1
53.	David C. Mountain Boston University Boston, MA	1
54.	Melissa Soldevilla NOAA/NMFS Southeast Fisheries Science Center Miami, FL	1

55.	Brandon L. Southall Southall Environmental Associates, Inc. Santa Cruz, CA	1
56.	David Moretti NUWC Newport, RI	1
57.	Michael Weise Office of Naval Research, Code 32 Arlington, VA	1
58.	Dan Costa University of California, Santa Cruz Santa Cruz, CA	1
59.	Lori Mazzuca Marine Mammal Research Consultants, Inc. Honolulu, HI	1
60.	Jim Eckman Office of Naval Research Arlington, VA	1
61.	Ari Friedlaender Duke University Beaufort, NC	1
62.	CAPT Robin Brake U.S. Navy Washington, DC	1
63.	Mary Grady Southwest Fisheries Science Center La Jolla, CA	1
64.	Lisa Ballance Southwest Fisheries Science Center La Jolla, CA	1
65.	Angela D’Amico SPAWAR San Diego, CA	1

66.	Amy Smith Science Applications International Corporation McLean, VA	1
67.	Peter Tyack Woods Hole Oceanographic Institution Woods Hole, MA	1
68.	Ian Boyd University of St. Andrews St. Andrews, Scotland, UK	1
69.	Simone Baumann-Pickering Scripps Institution of Oceanography University of California La Jolla, CA	1
70.	Lisa K. Baldwin Scripps Institution of Oceanography University of California La Jolla, CA	1
71.	Anne E. Simonis Scripps Institution of Oceanography University of California La Jolla, CA	1
72.	Mariana L. Melcon Scripps Institution of Oceanography University of California La Jolla, CA	1
73.	Daniel L. Webster Cascadia Research Collective Olympia, WA	1
74.	Daniel J. McSweeney Wild Whale Research Foundation Holualoa, HI	1
75.	Sabre D. Mahaffy Cascadia Research Collective Olympia, WA	1

76.	Jessica M. Aschettino Cascadia Research Collective Olympia, WA	1
77.	Tori Cullins Wild Dolphin Foundation Waianae, HI	1
78.	Alison Stimpert Naval Postgraduate School Monterey, CA	1
79.	Diane Claridge Bahamas Marine Mammal Research Organisation Abaco, Bahamas	1
80.	Charlotte Dunn Bahamas Marine Mammal Research Organisation Abaco, Bahamas	1
81.	Cathy Bacon Smultea Environmental Sciences, LLC Issaquah, WA	1
82.	Ana Širović Scripps Institution of Oceanography University of California La Jolla, CA	1
83.	Amanda Cummins Scripps Institution of Oceanography University of California La Jolla, CA	1
84.	Sara Kerosky Scripps Institution of Oceanography University of California La Jolla, CA	1
85.	Lauren Roche Scripps Institution of Oceanography University of California La Jolla, CA	1

86.	Brian Bloodworth National Marine Fisheries Service Silver Spring, MD	1